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# CONTENTS OF VOL. LI.


| | PAGE. |
|---|---|
| ADVERTISEMENT ... ... ... ... ... ... ... ... ... | ii |
| CONTENTS ... ... ... ... ... ... ... ... ... ... | iii |
| LIST OF PLATES ... ... ... ... ... ... ... ... ... | vi |
| OFFICERS OF THE COUNCIL, 1915-1916 ... ... ... ... ... ... | vii |


## GENERAL MEETINGS.

### THE INSTITUTION OF MINING ENGINEERS.


| 1916. | PAGE. |
|---|---|
| June 8th.—General Meeting (London) ... ... ... ... ... ... | 462 |
| Chairman's Opening Address ... ... ... ... ... ... | 462 |
| "The Health of Old Colliers." By J. S. Haldane, M.D., F.R.S. | 469 |
| Discussion ... ... ... ... ... ... ... | 477 |
| "The Estimation of Moisture in Coal." By T. F. Winmill, B.A., B.Sc. ... ... ... ... ... ... ... ... | 484 |
| "The Absorption of Oxygen by Coal.—Part VIII.—The Effect on the Absorption of the Size of the Coal-particles and the Percentage of Oxygen in the Air." By T. F. Winmill, B.A., B.Sc. ... ... ... ... ... ... ... ... | 493 |
| "The Atmospheric Oxidation of Iron Pyrites." By T. F. Winmill, B.A., B.Sc. ... ... ... ... ... ... | 500 |
| "The Absorption of Oxygen by Coal.—Part IX.—Comparison of Rates of Absorption of Oxygen by Different Varieties of Coal." By T. F. Winmill, B.A., B.Sc. ... ... ... | 510 |
| Discussion ... ... ... ... ... ... ... | 532 |
| "Notes on the History of the Safety-lamp." By F. W. Hardwick, M.A., and L. T. O'Shea, M.Sc. ... ... ... | 548 |
| Discussion ... ... ... ... ... ... ... | |


### THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.


| 1916. | |
|---|---|
| Feb. 8th.—General Meeting (Manchester) ... ... ... ... ... | 91 |
| Discussion of Dr. George Hickling's papers on "The Coal-Measures of the Croxteth Park Inlier" and "The Geological Structure of the South Lancashire Coalfield" ... | 91 |
| "The Connexions Between the North-Western European Coal-fields." By Prof. X. Stainier, D.Sc. ... ... ... ... | 99 |
| March 14th.—General Meeting (Manchester) ... ... ... ... ... | 208 |
| Death of Mr. Robert Winstanley and Lieutenant Laithewaite | 208 |
| "Carbon Dioxide as an Agent in Extinguishing Mine Fires, with Special Reference to Its Application at the Senghenydd Colliery." By Edgar C. Evans, B.Sc., F.I.C. | 209 |
| Discussion ... ... ... ... ... ... ... | 237 |
| Discussion of Mr. David E. Thomas's paper on "The Value of the Experimental Fan in the Mining Laboratory" ... ... | 241 |
| Discussion of Dr. George Hickling's paper on "The Geological Structure of the South Lancashire Coalfield" ... ... | 244 |

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.—*Continued.*

1916. PAGE.

April 11th.—General Meeting (Manchester) ... ... ... ... ... 266
Discussion of Prof. X. Stainier's paper on "The Connexions between the North-Western European Coalfields" ... ... 266
"Economies in Coal-Washing." By Sherwood Hunter ... 268
Discussion ... ... ... ... ... ... ... 281

THE MIDLAND COUNTIES INSTITUTION OF ENGINEERS.

1916.

May 6th.—General Meeting (Nottingham) ... ... ... ... ... 456
Discussion of Mr. C. Dickinson's paper entitled "Description of Water-dams in Coal at Netherseal Colliery" ... ... 456
Discussion of Mr. James Black's paper on "Forming a Shaft-pillar in Thin Seams" ... ... ... ... ... ... 457
Discussion of Mr. Samuel Dean's paper on "Modern American Coal-mining Methods, with Some Comparisons" ... ... 458
Discussion on Fuel Economy ... ... ... ... ... ... 459

THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS.

1916.

March 21st.—General Meeting (Leeds) ... ... ... ... ... ... 189
"Pit-Timber and Its Preservation." By Prof. Percy Groom, M.A., D.Sc. ... ... ... ... ... ... ... ... 190
Discussion ... ... ... ... ... ... ... 200
Discussion of Mr. Edward Lloyd's "Notes on the Uses and Markets of Bye-products Obtained from Coke-ovens" ... 204
Discussion of Prof. William George Fearnsides's paper on "Some Effects of Earth-movement on the Coal-Measures of the Sheffield District (South Yorkshire and the Neighbouring Parts of West Yorkshire, Derbyshire, and Nottinghamshire)" ... ... ... ... ... ... ... ... 207
May 27th.—General Meeting (Doncaster) ... ... ... ... ... 408
"Some Effects of Earth-movement on the Coal-Measures of the Sheffield District (South Yorkshire and the Neighbouring Parts of West Yorkshire, Derbyshire, and Nottinghamshire)."—Part II. By Prof. William George Fearnsides, M.A. ... ... ... ... ... ... ... ... ... 409
Discussion ... ... ... ... ... ... ... 449

THE MINING INSTITUTE OF SCOTLAND.

1916.

Feb. 12th.—General Meeting (Edinburgh) ... ... ... ... ... 154
Discussion of Mr. Marcel Gillieaux's paper on "Lining Shafts with Concrete Z-Blocks" ... ... ... ... ... ... 154
Discussion of Mr. Sam Mavor's paper on "Compressed Air for Coal-cutters" ... ... ... ... ... ... ... 157
Discussion of Mr. James Black's paper on "Forming a Shaft-pillar in Thin Seams" ... ... ... ... ... ... 166
"A Method for the Rapid Estimation of Oxygen and Black-damp in the Air of Safety-lamp Mines." By Henry Briggs 169
Discussion ... ... ... ... ... ... ... 187

THE MINING INSTITUTE OF SCOTLAND.—*Continued.*


| 1916. | PAGE. |
|---|---|
| April 8th.—Annual General Meeting (Glasgow) ... ... ... ... | 288 |
| Annual Report of the Council, 1915-1916 ... ... ... ... | 288 |
| Accounts ... ... ... ... ... ... ... ... | 290 |
| Election of Officers, 1916-1917 ... ... ... ... ... | 291 |
| Discussion of Mr. James Black's paper on "Forming a Shaft-pillar in Thin Seams" ... ... ... ... ... ... | 292 |
| Discussion of Mr. Henry Briggs's paper on "A Method for the Rapid Estimation of Oxygen and Blackdamp in the Air of Safety-lamp Mines" ... ... ... ... ... ... | 302 |
| "The Sinking and Equipment of a Circular Shaft." By James Nisbet ... ... ... ... ... ... ... | 305 |


THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.


| 1916. | |
|---|---|
| Feb. 12th.—General Meeting (Newcastle-upon-Tyne) ... ... ... | 35 |
| Discussion of Mr. Samuel Dean's paper on "Modern Coal-mining Methods, with some Comparisons" ... ... ... | 35 |
| "The Hirsch Portable Electric Lamp." By Hiram H. Hirsch | 61 |
| "The Logic of Trams." By John Gibson ... ... ... ... | 72 |
| Discussion ... ... ... ... ... ... ... | 84 |
| April 8th.—General Meeting (Newcastle-upon-Tyne) ... ... ... | 339 |
| Discussion of Mr. Samuel Dean's paper on "Modern American Coal-mining Methods, with Some Comparisons" ... ... | 340 |
| Discussion of Mr. Hiram H. Hirsch's paper on "The Hirsch Portable Electric Lamp" ... ... ... ... ... ... | 350 |
| Discussion of Mr. John Gibson's paper on "The Logic of Trams" ... ... ... ... ... ... ... ... | 350 |
| "The Influence of Incombustible Substances on Coal-dust Explosions." By A. S. Blatchford, M.Sc. ... ... ... | 369 |
| Discussion ... ... ... ... ... ... ... | 377 |
| June 3rd.—General Meeting (Newcastle-upon-Tyne) ... ... ... | 386 |
| Discussion of Mr. Samuel Dean's paper on "Modern American Coal-mining Methods, with Some Comparisons" ... ... | 386 |
| Discussion of Mr. Hiram H. Hirsch's paper on "The Hirsch Portable Electric Lamp" ... ... ... ... ... | 388 |
| Discussion of Mr. John Gibson's paper on "The Logic of Trams" ... ... ... ... ... ... ... ... | 388 |
| Discussion of Mr. A. S. Blatchford's paper on "The Influence of Incombustible Substances on Coal-dust Explosions" ... | 401 |
| "Memoir of the Late George May." By Charles L. Dobson. | 402 |


THE NORTH STAFFORDSHIRE INSTITUTE OF MINING AND MECHANICAL ENGINEERS.


| 1916. | |
|---|---|
| Jan. 17th.—General Meeting (Stoke-on-Trent) ... ... ... ... | 1 |
| Institute Roll of Honour ... ... ... ... ... ... | 1 |
| "High-speed Air-compressors for Mining Work." By J. M. Walshe, A.M.I.E.E. ... ... ... ... ... ... | 2 |
| Discussion ... ... ... ... ... ... ... | 23 |
| March 27th.—General Meeting (Stoke-on-Trent) ... ... ... | 245 |
| "Notes on the Specification of Iron and Steel Suitable for Colliery Use." By W. Simons ... ... ... ... ... | 245 |
| Discussion ... ... ... ... ... ... ... | 257 |

PAGE.
INDEX ... ... ... ... ... ... .. ... ... ... ... 725

---

## LIST OF PLATES.

| | TO FACE PAGE. | | TO FACE PAGE. |
|---|---|---|---|
| I., II. ... ... ... ... | 22 | VI. ... ... ... ... ... | 403 |
| III. ... ... ... ... ... | 84 | VII. ... ... | *in pocket at end.* |
| IV., V. ... ... ... ... | 236 | VIII. ... ... ... ... ... | 448 |

---

ANY PUBLICATION OF A FEDERATED INSTITUTE MAY BE PLACED AT THE END OF THE VOLUME, *e.g.*, "ANNUAL REPORT," "LIST OF MEMBERS," ETC.

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## THE NORTH STAFFORDSHIRE INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,
HELD AT THE CENTRAL SCHOOL OF SCIENCE AND TECHNOLOGY, STOKE-ON-TRENT, JANUARY 17TH, 1916.

MR. JOHN GREGORY, PRESIDENT, IN THE CHAIR.

The SECRETARY read the minutes of the last meeting, which were confirmed and signed.

The following gentleman, having been previously nominated, was elected:—

MEMBER—

Mr. ISAAC WILLIAM CUMBERBATCH, 14, Vine Street, Stoke-on-Trent.

### INSTITUTE ROLL OF HONOUR.

The PRESIDENT (Mr. John Gregory) offered the congratulations of the Institute to Prof. John Cadman, C.M.G., Lieutenant James Cadman, D.S.O., R.N.V.R.; and Lieutenant Charles J. Cadman, M.C., R.E., on the distinctions recently conferred on them by His Majesty the King; and, on the suggestion of Mr. A. M. Henshaw, to Captain Robert Yates.

Mr. J. M. WALSHE read the following paper on "High-speed Air-compressors for Mining Work":—

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# HIGH-SPEED AIR-COMPRESSORS FOR MINING WORK.

BY J. M. WALSHE, A.M.I.E.E.

*Introduction.*—In presenting this paper, the writer desires to point out that the present abnormal times and the exigencies of business in a Government-controlled factory are not favourable for the production of papers involving a great deal of research-work and original investigation, and he would, therefore, crave the indulgence of the members for any consequent deficiencies.

In the early days of electric supply, the slow-speed steam-engine was practically the only source of power for the production of electricity. As electric-supply stations increased their output, and economy of space became a consideration, the high-speed vertical direct-coupled steam-engine made its appearance, and to a considerable extent took the place of the slow-speed sets. Subsequently, the growing demand for power units larger than could be successfully undertaken by reciprocating engines opened up the field for the modern steam-turbine.

Air-compressing machinery appears to be developing along the same lines. The slow-speed compressor is giving place to the high-speed type, with its greater economy of material and space; and, where very large units are required, the turbo-compressor is supplying the need.

In the very large air-supply stations on the Rand, turbo-compressor units of a capacity of 20,000 and even 50,000 cubic feet, requiring 4,000 to 13,000 horsepower, are quite a commercial proposition, and have proved a practical success.

Air-compressors of this size are, however, very exceptional, and the high-speed reciprocating compressor is quite capable of dealing with the highest outputs so far required in this country; and, in the hands of manufacturers experienced in the design of high-speed steam-engines, a very high standard of reliability and efficiency in operation is obtained.

Units of 1,000 to 1,300 horsepower are being successfully worked, and, owing to the relatively high speed of revolution, the weight of the parts and the space taken up are comparatively small. The speed, too, in the case of electrically-operated compressors, assists in keeping down the dimensions of the motor, and permits of the motor being directly connected.

The so-called "high-speed" or more correctly quick-revolution type of compressor is now extensively used in mines and collieries, and any information concerning it should be of general interest.

For the air-pressures required for power purposes in mining work, two-stage compression, with an intercooler between stages, is the design usually adopted in best practice.

It is not the writer's intention to describe a variety of high-speed air-compressors, as representative types were very fully dealt with in a recent paper read by Mr. G. Blake Walker before the Midland Institute of Mining, Civil, and Mechanical Engineers.* The writer proposes to select as an example of this type of compressor the one with which he is most familiar, and which is probably more largely used than any other, at any rate in England and the Colonies, namely, the double-acting two-cylinder two-crank type with automatic light-plate air-valves, and with the working parts lubricated on the forced-lubrication principle.

Figs. 1 and 2 (Plate I.) are sectional drawings of such a compressor, so arranged as to be operated by an electric motor. The design is so simple as to need very little explanation. The air-valves are placed on the side of the air-cylinder, in which position they are readily accessible and leave the ends free for the water-jackets; and, seeing that the compression is mainly done at the ends of the stroke, this is a very desirable arrangement.

In this design it is impossible for oil from the crank-chamber to be carried up into the air-cylinder, as there is a distance in excess of the full stroke of the compressor between the cylinder and casing stuffing-boxes. Another good feature is that piston-rods are used and not trunks. Although the differential trunk is a very usual design, and may be necessary in the case of small single-crank compressors, it is one which should be avoided whenever possible. It will be appreciated that a trunk is much

* *Trans. Inst. M. E.*, 1913, vol. xliv., page 629.

more difficult to keep airtight than a piston-rod, and that a trunk working in and out of a crank-chamber is liable to carry up a great deal of oil, whilst at the same time permitting air to pass down. Apart from the waste of oil, the oil thus carried up may become partly carbonized on the air-valves or distributed throughout the air-system, to the detriment of the hoses. An even more serious objection is that, if the air becomes heavily charged with oil-vapour, dangerous explosions may occur in the air-discharge piping or air-receiver.

If a trunk is used (and its use is almost imperative in the case of single-crank two-stage compressors), the compressor should be so designed that the trunk does not pass into the crank-chamber, as illustrated by Figs. 3 and 4 (Plate I.). With the differential trunk-piston design, the final compression takes place in the annular space between the trunk and the air-cylinder, and thus not only are the trunk packings subjected to the final air-pressure, but also the first-stage piston packing-rings. This increases greatly the possibility of serious air-leakage, and impairs the efficiency by increasing the friction. In the two-crank design, the circumference for leakage of piston-ring and packing is only a quarter of that in the differential trunk design, and, moreover, the difference in pressure on the two sides of the pistons is less, which tends to reduce the leakage. For the rest, the forced-lubrication system is too well known to need description, but a word may be said concerning the air-valves, a most important part of any compressor.

*Automatic Air-valves.*—Fig. 31 in the text illustrates a most efficient valve of this type. No. 1 is the valve-seat, and No. 2 the valve-guard, both of which are made of cast-iron. In the valve-guard are recesses for four closing springs (No. 3). Next to the seat comes the valve-plate (No. 4), made of thin tempered steel and perforated to give a multiple opening. The slits on each side of the central portion should be noted in particular; the plate being cut through, the parts marked No. 8 are ground down and especially tempered to form springs, which enable the valve-plate to rise and fall through the small amount of its lift uniformly and without friction. Next above the valve-plate is the lift-washer (No. 5), and then the cushion plate (No. 6), made of thin steel, its function being to soften the blow of the valve-

plate when lifting. No. 7 shows the complete valve with all the various parts in position.

As the working part of the valve is made of a tempered steel plate only $\frac{1}{16}$ inch or less thick, it has the advantage of extreme lightness, especially when considered in proportion to its surface area. As the lift is only about equal to the thickness, and the valve-plate is guided in a perfectly frictionless manner, it is obvious that it will not be liable to hammer itself or its seat to pieces, and can be depended upon to continue to work for an indefinite period without failure, and without noise.

As previously stated, this type of compressor is especially

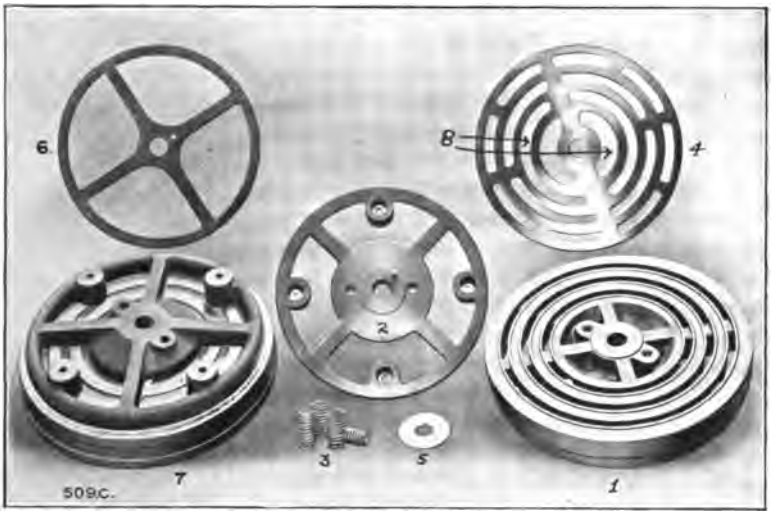


FIG. 31.—AUTOMATIC AIR-VALVES.

adapted for direct connexion to electric motors. The use of spur or helical gearing between the motor and the compressor should be avoided whenever possible, as (even if the cost of the motor is thereby reduced) the resulting loss of efficiency and the possibility of noise and trouble with the gear discount largely any saving in price effected. In the case of motor-driven slow-speed compressors, the use of ropes, belts, or other speed-reduction gearing is a common practice, and the consequent loss in overall efficiency is one of the drawbacks inherent to that type of machine.

A vertical high-speed compressor of a capacity of 4,000 cubic feet per minute takes up a third of the space required by a hori-

zontal slow-speed compressor of the same capacity; and, as the former requires much smaller foundations, it is evident that the cost for buildings to accommodate it must be less than in the case of the latter.

Fig. 32 in the text shows an external view of a motor-driven compressor of the design just described; Fig. 33 shows an external view of a steam-driven compressor, the steam-cylinders being superimposed above the air-cylinders.

The design of the intercooler is shown diagrammatically in Figs. 5 to 8 (Plate I.). It will be observed that there is a cen-

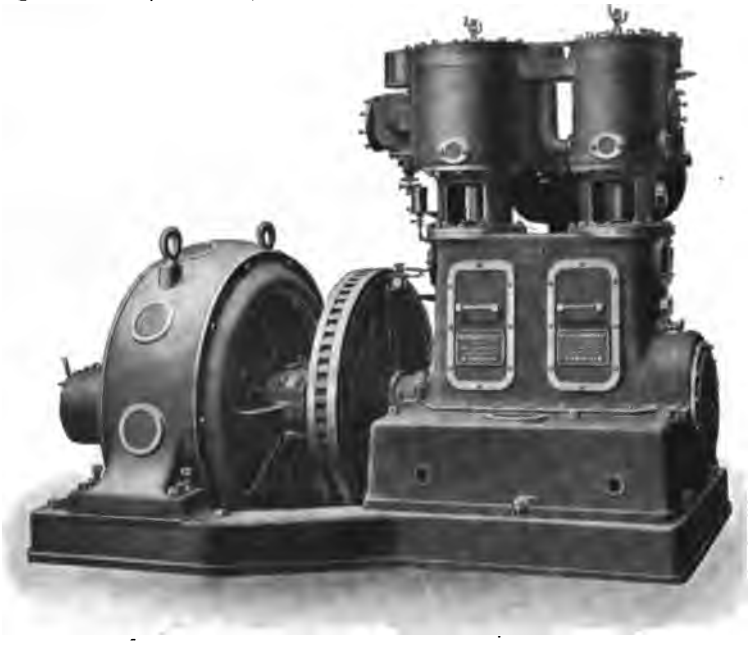

FIG. 32.—MOTOR-DRIVEN AIR-COMPRESSOR.

tral diaphragm plate supporting the tubes at a point midway of their length. The air that enters divides on this plate, and follows the course of the arrows, passing four times both upwards and downwards. The cooling-water is also arranged to pass four times upwards and downwards in a direction opposite to the air. The result is a very efficient intercooler, the air usually passing away to the second stage at a lower temperature than that at which the cooling-water leaves the intercooler. The tubes and tube-plate are of brass, similar in design to the best surface-

condensers, and can be removed for cleaning. The allowance of cooling surface depends to some extent, of course, on the temperature of the cooling-water, but is usually at the rate of 1 square foot for every 4 or 5 cubic feet of free air compressed per minute.

FIG. 33.—STEAM-DRIVEN AIR-COMPRESSOR.

The same design with a strengthened casing makes a very efficient after-cooler. There is a growing tendency, doubtless based on experience gained, to use after-coolers, presumably to improve the quality of the air. A great deal of the moisture in

the air is condensed in the after-cooler, and any oil or dirt which may have come through the compressor is also deposited there. Whether the use of cleaner and drier air offers advantages sufficient to warrant the extra expense of an after-cooler is a question which the writer would like the members to discuss.

A great point in favour of the adoption of the turbo type of compressor for colliery or mining work is that exhaust-steam can be used in the turbine operating the compressor; but the writer wishes to point out that the exhaust-steam can be utilized more economically by coupling the exhaust-steam turbine

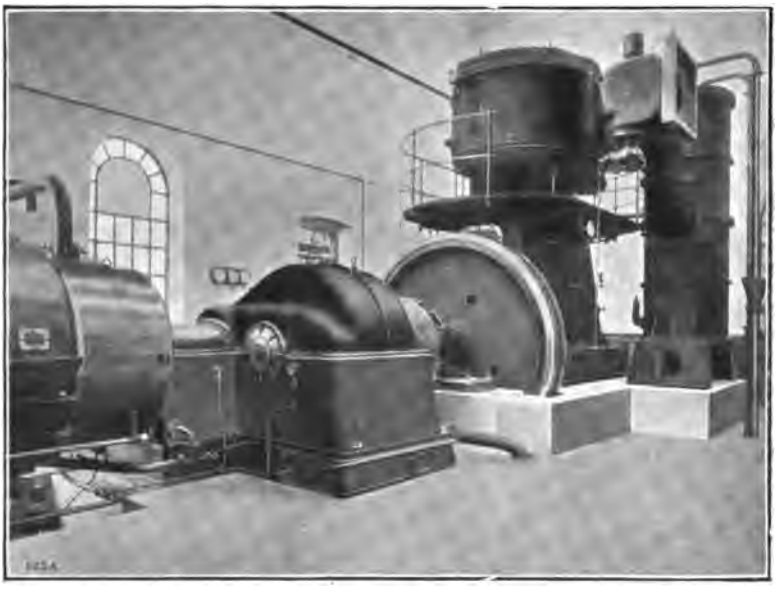

FIG. 34.—TURBINE-GEAR-DRIVEN AIR-COMPRESSOR.

through gearing to a high-speed reciprocating compressor. Such a plant has been in successful operation for three years past at the Glass Houghton Colliery of the Glass Houghton & Castleford Collieries, Limited, and has proved a practical and commercial success. Before this novel combination was adopted, the direct-driven turbo-compressor received full consideration; but, from estimates received from a large number of makers, both British and Continental, it was apparent that a turbo-compressor capable of dealing with 6,600 cubic feet of free air and delivering that quantity at a gauge-pressure of 70 pounds

per square inch would require at least 21 per cent. more power to operate it than a reciprocating set.

The efficiency of turbo-compressors may have been improved of late years: mechanically, they are greatly improved, but they are still far from being as efficient as reciprocating compressors of equal output. Moreover, in mining work, where necessarily compressors often run during some portion of the 24 hours at loads much below the full load, the reciprocator possesses still greater advantages, as, for reasons which will be stated later on, the efficiency of turbo-compressors is very low at the lighter loads.

It was, therefore, decided to instal the plant illustrated in Fig. 34 in the text. The air-compressor is of the vertical two-crank double-acting type, suitable for the specified duty when running at a speed of 163 revolutions per minute, and fitted with automatic plate-valves of the kind previously described. The turbine is of the mixed-pressure type, and the gearing of the double helical type supplied by the Power Plant Company, the bearings being lubricated under pressure from the system which supplies the turbine. Flexible couplings are fitted on both sides of the gearing. The gearing first supplied was not entirely satisfactory; but, as a result of certain modifications that were made, the initial difficulties were overcome, and the success of the gear drive is now beyond question.

In consequence of the satisfactory performance of this plant, another similar plant of slightly smaller dimensions is now in course of construction, and the writer considers that, as the advantages of this combination become more widely known, it is likely to be generally adopted, although for units of considerably larger output the turbo-compressor will hold the field.

As is the case with steam-turbines, the efficiency of turbo-compressors improves with the size, and for the very large sizes in use on the Rand the efficiency, if not equal to that of a reciprocating compressor, is still not much below it, and their low first cost is greatly in their favour.

*Efficiency.*—When the performances of compressors is contrasted, the only satisfactory basis of comparison is the overall efficiency. When a comparison is made between steam-driven compressors running under similar conditions of steam-supply and air-output, the number of cubic feet of free air compressed per pound of steam consumed is a very convenient figure for the overall efficiency. The equivalent figure for an electrically-driven compressor is the number of cubic feet of free air com-

pressed per kilowatt input to the motor. These expressions are, however, unsuitable when compressors operating under dissimilar conditions are compared, and it is better to state the overall efficiency as the ratio of the power available in the air delivered to that supplied to the engine or motor driving the compressor.

There is a natural tendency, on the part of manufacturers whose machines may show a specially good intermediate efficiency, to make the most of that particular feature; but each stage in the process of compression should be equally good, if a high overall efficiency is to be obtained. A high volumetric efficiency, for instance, does not necessarily imply a highly efficient compressor. As a matter of fact, a low volumetric efficiency may indicate liberal ports and valves, and consequently very small pressure losses in the compressor, resulting in a high overall efficiency.

When compressors were bought and sold on the "swept" volume of the air-cylinders, and not on the actual quantity of air compressed, the volumetric efficiency was a matter of great importance to the purchaser. Nowadays, compressor contracts are usually based on compressor output, and, provided that the compressor yields its full specified output of air, the volumetric efficiency is of little interest to the user. So long as the purchaser obtains the specified output of air compressed to the required pressure by the consumption of not more than the specified amount of steam or electrical energy, he need not trouble himself about the volumetric efficiency or any of the other various efficiencies which are so often quoted.

Fig. 9 (Plate I.) is a diagram illustrating the various losses and efficiencies in a steam-driven compressor. It was constructed from figures obtained on the official trials of a high-speed steam-driven compressor of a capacity of 3,530 cubic feet of free air per minute, discharging at an air-pressure of 100 pounds.

The areas *A*, *B*, *C*, and *D* represent to scale the available horsepowers at various stages. The shaded areas are the losses at each stage. *A* is the theoretical horsepower available in the steam, based on the adiabatic heat drop between the initial and final steam pressures; *B* is the indicated horsepower in the steam cylinders; *C* is the indicated horsepower in the air-

cylinders; and $D$ is the theoretical horsepower available in the air-discharge, based on isothermal compression. The shaded portion in $B$ represents to scale the heat wasted in the steam-cylinders, that in $C$ the power wasted in friction, and in $D$ the power wasted in heat and air-friction in the air-cylinders.

The overall efficiency is the ratio $\frac{D}{A}$, which for this particular compressor was 43 per cent.

The ratio $\frac{B}{A}$ = the thermal efficiency of the engine,

$\frac{C}{B}$ = the mechanical efficiency,

$\frac{D}{C}$ = the compression efficiency,

and $\frac{D}{B}$ is usually termed the "commercial efficiency."

The overall efficiency of an electrically-driven compressor is the ratio of the isothermal horsepower in the air discharged to the electrical horsepower input to the motor. A good modern direct-coupled high-speed motor-driven compressor will show an overall efficiency of from 60 to 65 per cent. The higher overall efficiency in the case of the electrically-driven compressor is explained by the fact that the conversion of electrical energy into work is (in our present state of knowledge) a much more efficient process than the conversion of the heat energy in steam into work.

*Air-control.*—The economical working of a compressor is affected to a large extent by the means adopted for controlling the air-output. The most economical method is to vary the speed of the compressor in proportion to the demand for air.

Figs. 10 and 11 (Plate I.) show an air-governor which, working in conjunction with a centrifugal speed-governor, controls the speed of a steam-driven air-compressor. For air-pressures up to the full working pressure, the compressor is under the control of the centrifugal governor. When the working air-pressure is exceeded, the air-governor takes control, varying the speed in proportion to the demand for air. It operates in the following manner:—

$A$ is the air-governor cylinder, $B$ a plunger, $C$ a relay or pilot valve, and $L$ a rocking lever pivoted at $N$. When the air-

pressure is below the working pressure, the relay-valve *C* is held in its inner position, as shown, by the springs *G* at the end of the lever *E*. In this position the air-pressure is shut off the cylinder *A*, which is open to the atmosphere through the exhaust port, and the speed of the compressor is under the control of the centrifugal governor. Excess air-pressure lifts the valve *C* against the resistance of the springs *G*, shutting the exhaust-port and admitting pressure behind the plunger *B*. The plunger moves outwards, depressing the near end of the lever *L* and raising at the other end the vertical rod attached to the steam throttle-valve, thus reducing the supply of steam to the engine. Since the lower ends of the springs *G* are connected to the lever *L*, the movement of that lever increases immediately the tension on them, the relay-valve is forced back to a middle position over the cylinder port, and the gear remains stable in the new position. On any further rise in air-pressure the operation is repeated, and the steam-supply is further reduced.

A falling air-pressure has the reverse effect. The lower air-pressure under the relay-valve *C* is insufficient to maintain it in the middle position, and under the pressure of the springs *G* it moves inwards, allowing some of the air behind the plunger *B* to escape into the atmosphere. The plunger *B* is thereupon moved inwards by the main control spring *H*, relieving the tension on the springs *G*, and allowing the relay-valve to centre itself again. With a variation in the air-pressure of less than 5 per cent., the range of speed obtainable is about 5 to 1. Without the relay principle embodied in this design the speed control would be intermittent, that is, the compressor would run either at full speed or at the minimum speed. Although a common arrangement, it is not so efficient as the one just described.

Variable speed can also be secured in connexion with compressors driven by direct-current motors, and to a limited extent in the case of alternating-current motors; but, owing to the increased cost of the motor, variable speed is not usual for electrically-driven compressors of large size. Automatic stopping and starting devices are occasionally used for the smaller sizes, but in general electrically-driven compressors are so devised as to run at constant speed.

A common form of unloading device for constant-speed com-

pressors is the automatically operated air-inlet throttle-valve. When the action is intermittent, this is the simplest and most efficient arrangement. When the inlet-valve is designed to throttle the air gradually, there is a considerable waste of power at light loads, and the temperature of the air discharged is liable to become excessive.

Fig. 12 (Plate I.) illustrates an automatic air-inlet valve which is intermittent in its action. Under normal conditions the inlet-valve is full open, and there is no waste of power due to wiredrawing the air. Excess air-pressure shuts the valve completely, and the no-load losses are practically confined to the unloaded friction of the compressor. Since no air is being drawn in, there is no churning of the air through the delivery or suction-valves.

Indicator-diagrams taken at no load will show at once whether the governing is economical or not. The lower the residual power in the air-cylinders is, the better is the light-load efficiency.

Fig. 13 (Plate I.) is an indicator-diagram* taken from a compressor fitted with an unloading device by which the air-delivery valves are held open at times of light load. The full-line diagram is the unloaded condition, the dotted line the full-load diagram. The area of the unloaded diagram is 36·7 per cent. of that of the full-load diagram. This, therefore, is a very inefficient arrangement.

Fig. 14 (Plate I.) illustrates the loaded and unloaded diagrams taken from a high-speed air-compressor fitted with an air-inlet throttle-valve. The shaded areas are the no-load diagrams. In this case the unloaded diagrams are only 3·6 per cent. of the area of the full-load diagrams. In Fig. 15 (Plate I.) are curves showing the efficiencies obtained at various loads by the different methods mentioned.

Where automatic stopping and starting gears are used, the air-pressure at the discharge side of the compressor should be released before the motor is started again. This necessitates a non-return valve in the air-main close to the compressor and a relief-valve automatically operated by the motor starting gear.

Owing to the inertia of the flywheel and moving parts at full speed, the full-load torque is proportional to the mean pressures

* Reproduced from *Compressed Air*, by G. D. Hiscox, 1902, page 298.

in the air-cylinders; but, when starting, the flywheel effect is absent, and the resistance to rotation is that due to the maximum discharge pressures on the air-pistons.

A compressor of a capacity of 450 cubic feet, driven by a 440-volt direct-current motor, recently tested by the author, required about twice the full-load current at starting when the motor had to start up with the full air-pressure on the compressor outlet-valves. When the air-pressure at the discharge was released, the starting current fell to less than 50 per cent. of the full-load value. Other tests carried out on the same compressor have demonstrated that relief of the pressure at the discharge is much more effective in reducing the starting torque than shutting off the air at the inlet.

*Leakage Tests.*—The maintenance of a high standard of economy involves occasional tests for piston and air-valve leakage. When indicators are available, internal air-leakages can be detected readily by the shape of the diagram, or by comparing the apparent volume of free air drawn in with that shown at the discharge. The temperature and pressure of the air entering and leaving the cylinder must be known in order to calculate the amount of air that is passing.

In Fig. 17 (Plate I.) $V_1$ represents the full cylinder volume,
$V_2$ the air-inlet line, and
$V_3$, measured along the discharge pressure line, the air delivered.

If $T_1$ and $P_1$ be the inlet-air temperature and pressure absolute, $T_2$ and $P_2$ the discharge temperature and pressure absolute, and $C$ the swept volume of the cylinder per minute, then the apparent quantity of free air drawn in and compressed per minute measured at the inlet line is—

$$\frac{V_2}{V_1} \times C.$$

When measured at the discharge line, it is—

$$\frac{V_3}{V_1} \times \frac{P_2 T_1}{P_1 T_2} \times C.$$

As these two quantities should agree, any considerable discrepancy between them is an indication of internal air-leakage either past the air-valves or the piston.

Fig. 16 (Plate I.) is a diagram taken from the first-stage cylinder of a two-stage compressor in which the air-*suction* valves

were leaking badly. Fig. 17 (Plate I.) is a diagram taken from the same air-cylinder after the suction-valves were made airtight. With leaky suction-valves the apparent quantity of free air drawn in is much greater than that shown at the discharge, and the first-stage discharge pressure is lower than normal. With the valves in good order, there is a very fair agreement between the free air indicated at the inlet and the discharge.

Fig. 18 (Plate II.) is a first-stage air-cylinder diagram in which the air-*delivery* valves were leaky. Fig. 19 (Plate II.) is a diagram taken from the same cylinder with the delivery-valves in good order. In this case the apparent free air drawn in is much less than that indicated at the discharge—the opposite effect to that produced by leaky suction-valves. The first-stage discharge pressure is again lower than normal. Leaky air-valves in the second-stage cylinder have a similar effect on the diagram, but the intercooler pressure is raised above the normal; and a pressure-gauge fitted on the intercooler should prove a useful check on the state of adjustment of a compressor.

A standing test will often reveal leakages too small to affect the running intercooler pressure. To carry out a standing test, stop the compressor, leaving it connected to the full air-pressure in the receiver, and observe the discharge and intercooler pressure-gauges. When the air-valves are in a good state of adjustment, the pressure in the receiver and intercooler will remain stationary, or fall only very slowly. Leakage past the second-stage valve will cause the intercooler pressure to rise; on the other hand, leaky first-stage valves allow the air to escape from the intercooler and the pressure to fall.

If there are indicator cocks fitted to the air-cylinders, the leakage can often be traced to the offending valve or valves by opening the cocks in succession, starting at the first stage. When the air-valves are in good order, the flow of air from the open cock will be quite feeble, not sufficient to extinguish a candle held in the stream 6 inches from the cock.

*Air Pipework.*—Special consideration should be given to the arrangement and proportions of the pipework close to the compressor. Owing to the pulsating nature of the air-flow, surges can be set up which affect the efficiency of the compressor. If, for instance, the pipe on the inlet side is of the

critical length in proportion to its diameter, air-surges will be set up which, if their period synchronizes with the beat of the compressor, may become so much intensified as to increase greatly the flow of air into the compressor. The increased volume of the air passing is, of course, accompanied by an increase in the power required, and, when the compressor is electrically driven, this may cause an overload on the motor. In one instance, where the motor operating the compressor was considerably overloaded, it was found that elimination of the inlet-pipe resulted in a drop of no less than 40 horsepower in the power required to operate the compressor. When the inlet-pipe has happened to be of suitable proportions, the air-flow has been so stimulated that volumetric efficiencies in excess of 100 per cent. have been demonstrated.

In Figs. 20 and 21 (Plate II.) the indicator-diagrams show the effect of air surges in the inlet-pipe. Fig. 20 was taken when there was a long straight suction-pipe on the air-intake; whilst Fig. 21 is one from the same compressor, but with the inlet-pipe eliminated. Here the air-surge increased the output by 15·6 per cent. and the power required by 17 per cent.

This effect is not, of course, peculiar to high-speed air-compressors: cards showing the same characteristics have been obtained from slow-speed compressors. The surge can be eliminated by a considerable increase of the bore of the suction-pipe close to the compressor. From 10 to 15 feet of piping, of an area large enough to reduce the air-speed to about 10 feet per second, is effective in most cases.

The increased output obtained when the air-surge occurs on the suction side is some set off for the additional power required; but when the surge is on the discharge side, there is no similar compensation, and the extra work due to the surge is wholly wasted.

Fig. 22 (Plate II.) was taken from a compressor with a 6-inch bore outlet pipe, discharging into a large air-receiver about 30 feet distant from the compressor outlet. The loss during discharge shown by the shaded area amounts to 9·2 per cent. of the total area of the diagram. Fig. 23 (Plate II.) shows the effect of the introduction of 12 feet of piping 10 inches in diameter close to the compressor. The remaining 18 feet was the original pipe of 6-inch bore. The loss during discharge was reduced to 3·5

per cent. The air speed in the 6-inch bore pipe was 44 feet, and in the 10-inch pipe 15·75 feet per second. Surges on the discharge side can, therefore, be greatly minimized by increasing the pipe capacity close to the compressor.

These surging effects are naturally of greater importance the lower the delivery pressure is at which the compressor works; and in the case of a compressor operating at a pressure of 5½ pounds per square inch, such surging effects occurring in the inlet and discharge pipes have been known to increase the power required to operate the compressor by as much as 30 per cent.

It might be supposed that surging effects would be absent in the case of rotary or turbo-compressors, but such compressors are specially liable to be adversely affected in this way. With turbo-compressors, as the output is reduced a point is reached (generally about five-eighths load) at which the air begins to surge to and fro in the compressor, causing shocks, noisy working, and very high air-temperatures. This tendency to surging is responsible sometimes for serious difficulties in running turbo-compressors in parallel delivery into a common main. The remedy usually applied is to keep the output above the critical load by discharging part of the air direct to the atmosphere. To blow the surplus air to waste is undoubtedly the most inefficient method of controlling the output, and one that would not be entertained in the case of a reciprocating compressor.

*Straining Arrangements for Air.*—It is important—at any rate, if there is much dust about—that some adequate arrangements should be made for filtering the air, and the expense involved in so doing will prove to be amply repaid by the improved results derived from the air-compressing plant and tools. At a colliery there is almost invariably a great deal of dust, and in an extreme case it has been found that, not only have the airways into the compressor become choked with a caked composition of coal-dust and oil, but that the clearance-spaces in the air-cylinders have been entirely filled up, causing the compressor to knock. The dirt also accumulates on the valves, thus increasing their weight, and therefore the risk of breakage.

The intercooler efficiency is also impaired, with a resulting increase in the air-temperatures. Undoubtedly a considerable proportion of the dirt is intercepted in the receiver, but some is certainly carried on into the tools, increasing their wear and tear and liability to derangement. On the whole, there is no doubt whatever that an air-filter is a paying proposition. In some cases where it has not been considered advisable to incur the expense of such a filter, the inlet-pipe has been removed and the compressor arranged to draw its air-supply from the compressor-house, thereby avoiding to some extent the dust; but this course is not advisable, as the noise arising from the air-inlet is very unpleasant, to say nothing of the fact that the air is, as a rule, being drawn from the compressor room at a higher temperature than that outside.

The arrangements for the filtering of the air must be adequate for the purpose. It is useless to set up, as occasionally supplied, a frame of wire-gauze very little larger than the air-inlet pipe on the compressor. Such a sheet of gauze, if of fine enough mesh to filter effectively the air, very quickly becomes choked with dirt, and may go to pieces and pass into the compressor.

There are several fairly well-known patented systems of air-filtration, which, however, need not be described here. They have the advantage of being compact, but the only way of removing the dirt from some of them is to send the strainer cloths away to be cleaned, which is not, as a rule, a very practicable process.

Figs. 24 to 27 (Plate II.) show a simple and comparatively inexpensive straining arrangement which was developed on the Rand, where there is a vast quantity of dust, and it has become almost standard in that area. The straining material is of the best cocoanut matting supported by wire-netting, and is enclosed in wooden frames, which are so arranged as to form a box, into which the inlet-pipe of the compressor is introduced.

The frames are secured by bolts and fly-nuts, and are thus easily removable when it becomes necessary to clean them, a spare frame being substituted. Experience has shown that the area of matting should be about 50 to 60 times the sectional area of the inlet-pipe. The dimensions of the strainer vary, of course, with the size of the compressor, and may either

consist (as in the case of the present illustration) of a box carried on the wall of the compressor-house and suitably protected against the weather, or (as shown by Fig. 35 in the text) may be of much larger dimensions. Fig. 35 shows the strainer-houses in connexion with four high-speed compressors, each of a capacity of 6,500 cubic feet, at the New Modderfontein Gold Mine on the Rand. There are two houses, each having thirty-two strainer frames of the sort described. The houses stand apart from the main building, and the air is carried into the compressor-house by culverts under the floor, into which the

FIG. 35.—AIR-STRAINER HOUSES AT NEW MODDERFONTEIN MINES.

inlet-pipes of the compressor dip down. Fig. 36 in the text shows the interior of the air-compressor house. Each of the four compressors is operated by an asynchronous motor of 1,000 horse-power, running at a speed of 163 revolutions per minute. A special characteristic of these compressors is that, influenced doubtless by previous experience, the mining engineer specified that the intercoolers should be so designed that the whole of the tubes could be readily lifted out and dropped into a soda-tank, in which they might be boiled for the removal of the grease. Reports received after more than two years' operation

showed, however, that very little dirt or grease had accumulated. Although each compressor was fitted with forty light-plate air-valves (160 in all), none of them had become broken after two years' running. The mining engineer considered that this, as also the cleanliness of the compressors and intercoolers, was attributable largely to the excellence of the arrangements made for cleaning the air, and, further, to the very small

FIG. 36.—INTERIOR OF NEW MODDERFONTEIN AIR-COMPRESSOR HOUSE.

quantity of oil used for internal lubrication of the air-cylinders. Less than a pint of oil is used in each of these large compressors for a continuous run of 24 hours. About three-quarters of this is used in the air-cylinders and the rest in the crank-chamber.

Figs. 28 and 29 (Plate II.) show the lay-out of two electrically-driven air-compressors, each of a capacity of 1,500 cubic feet working at a pressure of 100 pounds.

The air-filtering arrangement consists of frames such as those that have been described, with a roof to keep off the rain, the air-inlet pipe being carried underground. If necessary in the interests of the motor, the pressure can be relieved from the discharge-pipe before starting up by closing the 6-inch sluice-valve and by opening the safety-valve, gear being provided for the purpose.

It will be noted that the motor is directly connected to the compressor without the interposition of a flexible coupling. Experience has shown that flexible couplings for compressor driving are liable to prove very troublesome, causing much more trouble, in fact, than they are ever likely to prevent. At the same time, in the absence of a flexible coupling, it is very necessary that the motor-shaft should be of ample dimensions, as very heavy stresses are liable to occur if torsional oscillations are set up by the interaction of the heavy revolving weights constituted by the flywheel and the rotor. For this reason a single-bearing motor is to be recommended whenever possible. The length of shaft necessary to accommodate the extra bearing between the rotor and the rotor-coupling is a weak feature in the two-bearing motor. With the single-bearing motor there is no necessity for a shaft at the coupling end, and the coupling can be cast in one piece with the rotor frame, the connexion being made of sufficient rigidity to resist torsional oscillations.

*Air-mains.*—Before this paper is brought to a conclusion, the author would like to draw attention to a useful diagram for solving problems in connexion with air-mains. Formulæ for calculating air-pipe sizes are somewhat complicated and tedious, and it is often necessary to arrive at the result by a series of approximations or trial solutions. In order to facilitate the solution of such problems, Prof. C. R. Richards, of the University of Illinois,* has evolved a transmission diagram for air by which problems pertaining to the flow of air in pipes may be solved quickly and with sufficient accuracy for ordinary requirements. Fig. 30 (Plate II.) is a reproduction of the diagram.

The use of this diagram is simple. If the volume of free air per minute, the length of pipe, the initial pressure, and the per-

* "Entropy-temperature and Transmission Diagrams for Air," *University of Illinois*, 1913, Bulletin No. 63.

missible drop in pressure are stated, the procedure is as follows:—From the length of pipe, in feet, follow a vertical line to its intersection with the volume line; from this point follow a horizontal line to its intersection with the initial-pressure line, and thence follow a vertical line until it intersects the horizontal line through the given pressure-drop. The position of this last point determines the proper pipe diameter. Any other combination of given data is handled similarly.

For example, let the length of the pipe be 2,000 feet, the volume of free air per minute 1,000 cubic feet, the initial air-pressure 100 pounds per square inch, and the permissible pressure-drop about 5 per cent. Then, following a vertical line from $L=2{,}000$ to $V=1{,}000$, a horizontal line to $P=100$, a vertical line to drop $=5$ per cent., it is found that a 4-inch pipe is the nearest commercial size available, although the drop for this size is about 6 per cent. The diagram is based on the following formula:—

$$V = 3{\cdot}061 \sqrt{\frac{d^5 p_1^2 (1 - r^2)}{KL}};$$

where $V$ = the number of cubic feet of free air at 70° Fahr. and 14·7 pounds absolute pressure flowing per minute;

$d$ = the measured diameter of pipe, in inches;

$r = \frac{p_2}{p_1}$ = the ratio of the final to the initial pressures;

$m = \frac{d}{4}$ for circular pipes;

$K$ = the coefficient of resistance;

$L$ = the length of the pipe, in feet; and

$p_1$ = the initial pressure in the pipe, in pounds per square inch absolute.

In plotting the chart, the value of $K$ has been assumed to be—

$$K = 0{\cdot}003 \left(1 + \frac{3{\cdot}6}{d}\right).$$

The accuracy of the formula is dependent upon the assumption of a correct value of $K$, for which, however, there is very little reliable data available. If it should be desirable to use $K_1$, another value for $K$ than the one given. the values of $V$ from the chart are to be multiplied by—

$$\sqrt{\frac{K}{K_1}}.$$

In a recent paper read by Mr. Sam Mavor before The Institution of Mining Engineers at Leeds, in September, 1915, attention was drawn to considerable discrepancies between the pressure-drops as calculated from various theoretical formulæ and the actual pressure-drops obtained on tests carried out by himself. If these tests are reliable, it would seem that the generally-accepted formulæ are liable to considerable error, and that to attempt to obtain exact results by long and complicated calculations is a waste of time. A labour-saving device such as this transmission diagram for air should, therefore, prove a great convenience.

In conclusion, the author acknowledges his indebtedness to Messrs. Belliss & Morcom, Limited, for permission to use the results of tests carried out in their test-house, and for the photographs and diagrams reproduced in the paper. His thanks are also due to the Director of the University of Illinois for permission to reproduce the transmission diagram for air.

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The PRESIDENT (Mr. John Gregory) said that the paper was one of the most interesting and practical that had been offered for some time. In recent years the use of compressed air in mines had to a certain extent given way to electricity, but nowadays it was increasing, owing to the restrictions placed on the use of electricity under certain conditions at the coal-face. The air-compressors of the past were generally of the horizontal slow-speed type, and had given good results. They were reliable and economical, but they had one drawback—they required heavy foundations and large engine-houses. He (Mr. Gregory) had recently put down a high-speed air-compressor on the lines indicated in the paper, and the results were admirable. One feature that Mr. Walshe had pointed out was the small amount of oil required for lubrication, and he (the speaker) could entirely corroborate his statement in that respect.

Mr. Walshe had stated that the turbo-reciprocating set was more economical than the centrifugal turbo-compressor for units of 6,000 cubic feet of air per minute; but that, in the larger sizes, the efficiency was more equal. It would be of interest to know the point at which the centrifugal compressor could compare in economy with the reciprocating

mains at the generator would be nearer 60 pounds, and that with pipes of good capacity, and the motor engines and cutters designed for pressures of 50 to 60 pounds, the best overall efficiency would be obtained, and therefore the greatest economy.

With respect to the question of efficiency, what they were concerned about in mining was the overall efficiency, not only of the generator, but of the pipes and motors; in fact, from the boiler to the end of the rope in the pit. They had to compare the horsepower in the steam with the horsepower delivered by the motor at, perhaps, a mile or two distant in the workings. Loss of power was often due, not to the generator, but to the failure to give proper attention to the pipe-work. They must have good plant and see that it was looked after properly; and, even then, they would have to be satisfied, in the case of compressed air, if they got 33⅓ per cent., or anything approaching that figure, as the actual useful effect in work done at the end of the air-main.

Mr. G. P. HYSLOP (Longton) said that he would have liked more information of other kinds of compressors besides the quick-revolution reciprocating type, with critical figures. With regard to the power that was to be used, particular stress had been laid on the efficiency of the electrically-driven compressor, but it must be for the colliery manager to decide what power he had available. If he had exhaust-steam available, it was clearly cheaper to use it in compressing the air directly. He (Mr. Hyslop) did not think that a case could be made out for generating electricity expressly for the purpose of compressing air. If they generated electrical power at a low cost by means of an exhaust-steam turbo-generator, it might in some instances be economical to use a large part of that for compressing the air, but *per se* a case could not be made out for generating electricity for compressing air afterwards. Low-speed compressors had done excellent work, even on the Rand; but it was noticeable that there was a tendency to increase the number of revolutions of the engines. However, he thought it quite possible—bearing in mind that the colliery manager wanted a machine which would run 300, if not 365 days a year—that the most efficient type would be found in medium-speed machinery, especially at small collieries, where the needful skilled supervision was not always available.

With reference to the comparison between the efficiencies of electricity and compressed air, it would be interesting to obtain some exact figures, because he distrusted the figures that had been made out generally in favour of electricity. He did not think that compressed air would come out so badly as the disciples of electricity would have them believe.

He could bear out from experience what Mr. Walshe had stated with regard to the objections to trunk-pistons. As to after-coolers, he thought that a number of receivers would act as an after-cooler. There was no doubt as to the advantages of the after-cooler. He had known of compressed-air pipes in a shaft on which one could hardly lay a hand on account of the heat, and the loss in friction must have been enormous. What form of power should be used depended to a great extent on whether a fairly constant load was available. An argument against the electrically-driven compressor was that a speed-control could not be applied. He agreed that the air should be strained, as if dust were deposited in the valve-chamber, it might then become incandescent.

Mr. J. W. Hartley (Stone) said that his experience of air-compressors dated back many years, and the high-speed compressors of the old days were certainly failures. He had nearly thirty years ago converted an old blowing-engine into an air-compressor, which, after working night and day for nearly thirty years, was still doing good service, whilst at the same colliery three high-speed air-compressors by well-known makers, after working only three years, were already on the scrap-heap. In a more recent case, an old type of slow-speed compressor had been superseded by a high-speed compressor; but the latter had proved a failure, and this and other instances had somewhat prejudiced him against high-speed compressors.

With regard to valves, he did not see why the makers could not design good mechanically-operated valves for high-speed compressors. He wondered how long the valves described could be guaranteed to work without breaking across the springs. The converted blowing-engine to which he had referred was still working with the disc-valves that he put in thirty years ago. Another argument against high-speed compressors was that if they were not entrusted to attendants used to high-speed engines,

they might easily get out of order; whereas the old type of engine would probably go on running with very little attention until the week-end, when it could be overhauled and any defects remedied. High-speed compressors should be installed in duplicate if the colliery manager was to feel at all safe. When a high-speed compressor broke down, it was often a far more serious matter than in the case of a slow-speed air-compressor.

It was obvious that the reversal of the reciprocating parts of an air-compressor was chiefly responsible for its wear and tear; also, clearance-space losses must by their greater frequency compare unfavourably with those in air-compressors, having a longer stroke and a slower speed. It became, therefore, a question of balancing the increased capital cost and efficiency of the slow-speed air-compressor against the possibly increased running charges and efficiency of the higher speeds. When dead weight was of importance, as in marine work, it was obvious that the high-speed compressor would hold the field against its heavier competitor.

Mr. JOHN CORK (Apedale) stated that valves of the type described had been working for five years, without a single failure, in a compressor at the works with which he was connected.

On the motion of the PRESIDENT, seconded by Mr. G. P. HYSLOP, a hearty vote of thanks was accorded to Mr. Walshe for his paper.

Mr. G. BLAKE WALKER (Tankersley) wrote that high-speed air-compressors for colliery work were now coming more and more into favour.

With regard to the special features of design, there was room for difference of opinion, and Mr. Walshe was certainly entitled to draw attention to the special features that were so well carried out in the Belliss-&-Morcom compressor with which he was identified.

He (Mr. Walker) thought that the leakage and trouble with trunk-pistons was overestimated; they undoubtedly formed an additional cooling surface, which was, however, less effective than the cylinder walls and cover.

He had at work a compressor of the trunk pattern in which,

after twelve months' working, no leakage occurred, and the wear of the piston-rings and liner was so small that the tool-marks were still visible. In the same compressor, at starting, 43 gallons of oil were put into the crank-case, and this quantity had not been augmented in the interval. Examination of the crank-case had shown that there was apparently no waste.

It would be interesting to hear whether anyone had made the experiment of driving a reciprocating compressor by tandem cylinders, operating either on exhaust or on live steam. Provided that the size of the unit was not sufficient to warrant a turbo-compressor, it seemed to him that much expensive and questionable gearing could be dispensed with by operating the compressor direct.

One great advantage of high cylinder clearance was that if the compressor was unequal to its work, it would on the same revolutions deliver more cubic feet of free air when the delivery pressure was reduced, and *vice versa*. It was, therefore, to a greater or less extent self-regulating in the air-discharge.

The arrangement of the inlet and the delivery-valve on the side of the cylinder was good, and the loss in volumetric efficiency was negligible. Low volumetric efficiency meant a quieter running machine, when this was due to cylinder clearance alone. The air which had not been expelled from the cylinder in re-expanding helped to give the necessary impetus to the moving parts during the early portion of their acceleration. An examination of indicator-diagrams from opposite ends of the cylinder would show that the reversal of stresses was much more gradual with high than with low cylinder clearance.

Perhaps one might suggest that there were not very many collieries which used high-pressure steam, and that there were many collieries where exhaust-steam turbines were being introduced, with the probable result that air-compressors would be driven electrically. An electric motor could not be slowed down like a steam-engine, and Mr. Walshe might very usefully add something on that point.

Mr. JOHN GIBSON (Kilmarnock) wrote that Mr. Walshe's paper formed a fitting sequel to Mr. Sam Mavor's recent communication on the subject.* The one dealt with the economical

* "Compressed Air for Coal-cutters," *Trans. Inst. M. E.*, 1915, vol. l., page 625.

supply of compressed air, and the other with its transmission and use.

The whole tendency for many years (both in regard to compressed air and to electricity) had been towards a higher speed. This had three main advantages: (1) it reduced the first cost, (2) it saved floor-space, and (3) it eliminated the losses due to belt-drives or gearing. It seemed to him that, until some means could be found to conserve the heat and to use hot air, compressed air would never be cheap. Still, where electricity was inadmissible, there was no other method of power-transmission that could even be compared with it.

Mr. Walshe's remarks on surging, rotary *versus* reciprocating compressors, leakage, efficiency, etc., were of the greatest interest and importance. In view of the probable increase in the number of underground compressors, the matter of straining arrangements was also an important one. The simple apparatus of cocoa-matting and wire-netting used on the Rand would probably give satisfactory results, and should prove a valuable and practical means for use in this country.

Mr. J. M. WALSHE (Birmingham) wrote, in reply to the President's remarks, that the point at which the centrifugal compressor could compare in economy with the reciprocator was outside the practical limit of size for the latter. Owing to their great size and cost, reciprocating compressors, even of the high-speed type, were not usually considered a practical proposition for more than 12,000 cubic feet of air per minute. On the data that he possessed of tests with very large centrifugal compressors, the efficiency even of the compressor of 20,000 cubic feet was still somewhat below that of a high-speed compressor of 6,000 cubic feet when tested under the same conditions and by the same authorities.

Comparative figures showing the relative efficiencies of various types of compressors were difficult to obtain: the published tests of air-compressors varied so greatly in method and in object that generally it was impossible to compare directly the results. In consequence of this difficulty, the only slow-speed compressors for which he could show the overall efficiency for comparison with the high-speed type were the following:—

| Reference No. | Type. | Speed, in revolutions per minute. | Output, in cubic feet per minute. | Air-pressure at delivery, in pounds per square inch. | Overall efficiency Per cent. |
|---|---|---|---|---|---|
| 1* | Slow-speed | 91 | 2,266 | 101 | 36·6 |
| 2† | do. | 68 | 2,408 | 85·2 | 42·6 |
| 3‡ | High-speed. | 240 | 3,530 | 100·0 | 43·0 |

* *A.E.G. Journal*, vol. l., No. 5.

† *Air-compressors and Blowing Engines*, by Charles H. Innes, M.A., 1906, page 238.

‡ This is the compressor referred to in the paper.

The efficiency of power-transmission of compressed air, as compared with electricity, had been discussed by Mr. Sam Mavor in his recent paper on "Compressed Air for Coal-cutters," and his remarks on this important subject were well worthy of attention.

Mr. Henshaw would be interested to know that high-speed steam-driven air-compressors having three cranks were being made. Two first-stage and one second-stage cylinders were arranged above the steam-cylinders of a triple-expansion engine, the high, intermediate, and low-pressure lines operating cranks at equal angles. This arrangement was excellent, and was, in regard to steam-consumption, more efficient than the two-crank compressor, the only drawback being its greater cost. For electric driving, an arrangement consisting of two two-crank compressors, with the motor between, giving in effect four cranks so far as even turning was concerned, presented many points of advantage, and was actually less costly than a two-crank set of the same capacity.

He could not claim to possess much knowledge concerning explosions, as the type of compressor with which he had to deal was singularly free from such troubles; but he might state that the most fruitful causes of explosions were bad design and neglect—bad design arising from the use of single-stage compression for pressures for which two-stage compression should be adopted, or compressors so designed that the crank-chamber low-flash oil found its way into the air-cylinders; or, again, badly-designed valves, or, if they were of good design, neglect to maintain them in good working order. Neglect to clean the compressor, together with an excessive oil-supply, whereby the air-cylinders and pipes became charged with an accumulation of coal-dust and oil, and the use of an unsuitable oil, were also contributory causes to explosion.

For high-speed compressors using saturated steam, an allowance of oil at the rate of a hundredth of a pint per 100 horse-power-hour should be ample for the lubrication of the steam-cylinders, with the same quantity for the air-cylinders. If the steam were superheated to 100°Fahr., the above allowance should be doubled for the steam-cylinders, and at 150°Fahr. this quantity should be trebled. With care and attention it was quite possible to run the air-cylinders with an allowance of half the above quantities. The best test, both as to the quality and as to the quantity of the oil supplied, was to open up the cylinders for examination occasionally, and to take note of their condition. It must be borne in mind that the air-cylinders required a different quality of oil from that used in the steam-cylinders. The air-cylinders were, as a rule, water-jacketed, and the temperatures were much lower in the air-cylinders than in the steam-cylinders, even when the steam was not superheated. Moreover, the air came in dry and more or less charged with dust, whereas the steam was moist and comparatively clean. Experience had shown that the dark cylinder-oil commonly used for the internal lubrication of steam-cylinders, when used in air-cylinders tended to cause the dust to collect, with resulting wear, so that a well-refined light hydrocarbon oil was best.

That the turbo-compressor should be less efficient than the reciprocating compressor was not surprising, when it was remembered how much less efficient a centrifugal pump was than a reciprocating pump. In the case of the turbo-compressor rapidly revolving fans imparted to the air velocity, which was afterwards converted into pressure in diffusers or nozzles. As the velocity and pressure obtainable in one wheel was very limited, a number of such fans must be arranged in series; and apparently the conversion of velocity into pressure even in the best designed turbo-compressors could not be effected at an efficiency much above 70 per cent.

It was true, as Mr. Henshaw had suggested, that a good running engine or compressor was the best advertisement for the maker, and, recognizing this, reputable firms made a point of sending a competent representative to inspect their productions at least once a year, and to advise their customers what adjustments were necessary.

The question whether the electrically-driven compressor with its overall efficiency of 60 to 65 per cent. had the advantage over

the steam-driven sets with an efficiency of 43 per cent. could only be decided by taking into account the cost of electricity, coal, labour, etc., in each particular case.

Mr. Henshaw had raised an interesting point concerning the ideal air-pressure for ordinary coal-mining work. The extra power required to compress air to a gauge-pressure of 100 pounds per square inch over that required for a pressure of 60 pounds was about 30 per cent., and the compression of air to a pressure of 90 or 100 pounds at the surface for use in the mine at 50 or 60 pounds appeared to be a very wasteful proceeding. The permissible loss due to friction in air-mains, however, depended largely on the relation between the cost of the pipework and the cost of production of the compressed air. Since the loss of power was less than the loss of pressure, owing to the increase in volume at the lower pressure, it was possible that, in certain circumstances, where pipes were expensive and coal cheap, the reduced cost of the smaller pipe with a large pressure-drop would more than compensate for the higher transmission losses.

He (Mr. Walshe) quite agreed with Mr. Hyslop that it was not possible to present a good case for generating electricity in order to compress air, if the cost of air-production was to be the only consideration; but, in practice, this was done regularly, showing that it might be a paying proposition for other reasons. For instance, electrically-driven air-compressors were sometimes placed down the mine as close as was permissible to the working-face, the capital expenditure in pipework and losses in transmission being thus much reduced. As a case in point, he might cite two motor-driven compressors supplied by his firm to a well-known diamond-mine. These compressors were placed in the mine 2,500 feet below the surface, and the result was so satisfactory that it was found possible to discontinue the use of a slow-speed steam-driven Riedler compressor of about 50 per cent. greater capacity at the surface.

Mr. Hartley's experience of high-speed air-compressors seemed to have been most unfortunate, and served to emphasize the importance of selecting only the best class of machine. Many hundreds of the type of compressor described in the paper were in daily use, giving thorough satisfaction to the users.

With respect to the possible breakage of the automatic plate-valves across the springs, Mr. Hartley would be reassured to know that breakages were very rare, and that valves made over

seven years ago were still in daily use, and likely to last for many years to come. High-speed air-compresssors did not easily get out of order, even in the hands of unskilled attendants, and their reliability and endurance had proved to be in no way inferior to that of the older slow-speed type.

The reversal of the reciprocating parts in an air-compressor did not necessarily increase the wear and tear; indeed, it might have the opposite effect. The energy stored in the reciprocating parts was given up towards the end of the stroke at a time when the pressure in the air-cylinders exceeded that in the steam-cylinders, and just when energy was required either from the motion-work or the flywheel, in order to complete the stroke. Energy given up by the flywheel was transmitted through the various bearings, thus increasing the wear and tear in them; whereas in the case of a well-designed high-speed compressor, where the reversal was quick and the force of inertia high, the reciprocating parts supplied the necessary momentum, and it was possible to use a smaller flywheel with a corresponding reduction in the load on the bearings. That the clearance-space losses were a negligible quantity was proved by the very high overall efficiencies obtained with this class of compressor.

Mr. G. Blake Walker was to be congratulated on having a trunk-pattern compressor giving such satisfactory results. Doubtless the interior of the trunk-piston did form an additional cooling surface; but, as the heat so got rid of was communicated to the oil in the crank-chamber, this was a very questionable advantage.

He agreed with Mr. Walker's remarks concerning the beneficial effects which resulted from a high proportion of clearance in the air-cylinders. An undue importance was often attached to small cylinder clearances.

Experiments in the direction of using exhaust-steam in a reciprocating engine were made by the writer's firm some years ago, but it was soon found that the only way of using exhaust-steam commercially for the production of power was in conjunction with a high vacuum, which it was now known could only be utilized satisfactorily in a turbine. Owing to the turbo-compressor being so inefficient in the smaller sizes, the combination of the gear-driven reciprocating compressor with the exhaust-turbine naturally presented itself as the best alternative to the arrangement suggested by Mr. Walker.

# THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,
HELD IN THE WOOD MEMORIAL HALL, NEWCASTLE-UPON-TYNE,
FEBRUARY 12TH, 1916.

MR. T. Y. GREENER, PRESIDENT, IN THE CHAIR.

The SECRETARY read the minutes of the last General Meeting, and reported the proceedings of the Council at their meetings on January 29th and that day.

The following gentlemen were elected, having been previously nominated:—

MEMBERS—

Mr. YASUKUMA MATSUBAYASHI, Colliery Manager, Daimyokoji, Karatsumachi, Sagaken, Japan.

Mr. JOHN CLARK TEMPLETON, Mechanical Engineer, The Maikop Pipeline & Transport Company, Limited, Apsheronskaya, near Maikop, Kuban District, South Russia.

ASSOCIATES—

Mr. HENRY BAYFIELD, Fore-overman, 41, Westcott Road, Tyne Dock, B.O., South Shields.

Mr. JOHN CLEMENT, Colliery Surveyor and Assistant Overman, 35, Station Road, Nostell, Wakefield.

Mr. CHRISTOPHER DEVENPORT, Fore-overman, 112, Talbot Road, South Shields.

Mr. GEORGE LOUDON, Colliery Under-manager, 1, Office Buildings, Harton Colliery, South Shields.

## DISCUSSION OF MR. SAMUEL DEAN'S PAPER ON "MODERN COAL-MINING METHODS, WITH SOME COMPARISONS."*

Mr. SAMUEL DEAN (Delagua, Colorado) wrote that it was a pleasure to him to find that his paper had been discussed by so

* *Trans. Inst. M. E.*, 1915, vol. l., pages 179 and 388.

large a number of mining men in different countries, and he hoped that what might be now called the "pit-car controversy" would not be allowed to die.

Mr. E. W. Parker and others disagreed with his statement that the principal reason why the United States of America led in production per man lay in the size of mine-cars used, and gave the credit to the employment of mechanical coal-cutters. He (Mr. Dean) claimed that even if there were not a single coal-cutter in use in the mines, America would still lead in output per man, and when the members had read his remarks they would understand why he made this statement. He agreed, however, that the extensive use of mechanical coal-cutters was one of the reasons why the United States was so far in the lead in that direction.

He wished particularly to direct attention to the remarks of Mr. Alfred J. Tonge, who was formerly a well-known English colliery manager. Mr. Tonge stated that there was need for serious reflection on the part of British colliery engineers as to how far they could go towards increasing the mine-car capacity, the improvement of rolling-stock, the permanent way, and the haulage facilities underground. One saw improvements in the surface equipment at British collieries, and recognized many Continental features. At a new colliery—say, Horden, on the south-east coast of Durham—thanks to German draughtsmen, there was a modern-looking heapstead building; but the underground methods were not much in advance of those of 30 years ago. These underground problems should not be allowed to rest until they had been threshed out and solved, and, naturally, after that improvements would continue indefinitely.

Mr. Tonge stated that the use of electric locomotives would not be considered likely in British mines, without giving his reason for this opinion; but the writer failed to see why that should be so. Such locomotives could be employed with comparative safety in all mines where open lights were used in the roadways, and there were open-light mines in Great Britain. Trolley-locomotives also would be permissible in all mines where other than permitted explosives were used for blasting purposes. It was a simple matter to treat haulage-roads with stone-dust, so as to prevent explosions of coal-dust through short-circuiting or from the arcing of trolley-wires. This matter was dealt with in the

discussion of a previous paper.* In mines giving off large quantities of gas much could be done by increasing the height on the secondary roads, and by employing three to six-horse or mule teams (six mules in a team), driven at top speed, and pulling fairly long trains of large tubs, with roller-bearing wheels over heavy rails. The leading mule would carry a permitted "bulls-eye" electric lamp on the collar, which would resemble a miniature searchlight; or the compressed-air locomotive could be used. This was not a terrible machine to have in a mine, and any aversion to its use vanished on closer acquaintance. If subsidiary rope haulage on secondary roads were preferred, the mule teams could be employed on such roads during periods preceding the installation of the rope-haulage. Single mules could be used between the furthest in-bye partings and the faces. A mule could "rough it" better than a horse underground; his "mine life" was longer; he knew when he was overloaded; and sometimes displayed a nearly human sense of danger.

It was doubtful whether endless-rope haulage was as efficient as it was stated to be. It was slow, and required a "little army" of men and boys to attend to it. In his opinion main-rope or main-and-tail-rope haulage, pulling up main down-brow or dip haulage-roads, with traction haulage on the levels, would beat it.

Mr. Tonge had spoken of the amount of brushing which would be necessary in British mines, and at first the brushing of both the top and the bottom in thin seams in America had appeared to him (Mr. Dean) to be an unnecessary expense; but he knew now that it was the proper course to follow, and that it "paid." Where new seams were being opened up, and face-conveyors employed, it would be madness not to use tubs of large capacity.

Different writers had drawn comparisons between "large" and "small" cars without stating the respective capacities of the cars, and he wished to explain that when an American spoke of a "small" car, he meant a car of from 1 to 2 tons capacity. From a British point of view a 2-ton car would be a large one.

Mr. W. R. Wilson had covered the ground in a very intelligent manner. He had drawn a moving picture of a man loading two tons of coal in a mine when 10-cwt. tubs were used. That man would fill his first tub, and would then wait until it had been

* *Trans. Inst. M. E.*, 1913, vol. xlvi., page 387; and vol. xlvii., page 136.

removed and replaced by an empty tub, or he would remove it himself and return with an empty one. He would repeat this operation four times, and each period of waiting or tramming would doubtless be of longer duration than the time required to fill the tub. On the other hand, if he received a 2-ton tub and filled that in the time required to fill two 10-cwt. tubs, including the periods of waiting or tramming, which was quite likely, it was at once apparent that his output would be doubled, and that only half the number of men would be required at the face to produce the same quantity of coal. A similar picture could be drawn all the way from the face to the shaft-bottom. When a putter, drawer, trammer, or driver took a 10-cwt. tub from the flat, shunt, siding, or parting, he travelled a certain distance to the coal-face and back, returning with half-a-ton of coal. If he had taken a 2-ton tub, he would have covered the ground in the same period of time, but would have returned with 2 tons of coal. In handling the tubs between the furthest in-bye parting and the shaft similar comparisons held good, and the number of haulage hands could be reduced at least 50 per cent. and yet deal with the same quantity of coal.

There was little difficulty in dealing with large tubs in deep shafts: they had been in use in the deep mines of South Wales for over half a century, as Mr. W. H. Routledge had pointed out; but it was difficult to induce the miners there to fill them to their fullest capacity, and on account of super-unionism the advantages of large cars had not been allowed to become known. In the United States over 35 per cent. of the bituminous output came from shaft mines where large cars were used.

Mr. G. S. Brackett spoke of the characteristic which went to extremes, and Mr. I. C. Parfitt had certainly gone to an extreme in his contribution to the discussion. He had painted life in the mining camps in very drab colours, yet it was true that many companies were building superior houses for their employees, and others were improving existing conditions; but about these improvements and the brighter side of the picture Mr. Parfitt was silent. That there was plenty of room for improvement he (Mr. Dean) would not deny, but Mr. Parfitt, having gone so far, might have explained the political system which permitted anyone to go into the "coal-mining business," and, in an effort to get rich quickly, to throw up a number of wooden "shacks" or

huts, and employ a butcher or a baker as superintendent or manager of the "mine." In a previous paper* he (Mr. Dean) had described and illustrated a modern mining village at Marianna, Pennsylvania.

The writer would now deal with the remarks of Mr. H. W. G. Halbaum, who had stated that the supposed superiority of the American miner sank to zero or became a minus quantity in thin seams, and that the general output of the British filler was 11 to 13 tons per shift in 3-foot seams. He (Mr. Dean) was delighted to hear this, but he was probably correct in assuming that these fillers did nothing but fill; they did no datalling, and many things that they might do for themselves were done for them by others. He (Mr. Dean) had not forgotten what he had to do for them. After serving his apprenticeship with a firm of mining engineers, he had secured employment as a dataller at some Lancashire collieries. As the colliers advanced, it was part of his duty to follow and take up "bottom" for them (the local mine term was "warrant"), and they made him carry props, etc., for them. He had long ago forgiven them for this, but, as conditions were to-day, they might do much of this work themselves, say, while waiting for empties, and at other times. Later on, he found that in the county of Durham the hewers had to employ deputies even to set their props for them. He mentioned these matters so that Mr. Halbaum might know that he had a little knowledge of coal-mining methods on both sides of the Atlantic. If the conditions were the same to-day—and he did not suppose that they had changed—his suggestion was that the staffs of datallers or shifters might be cut down, and that some of them might be sent to the coal-face. The services of so many in these departments were not at all necessary, and, if his suggestions were adopted, the national output would be raised. That this was possible was shown by the fact that one man alone was capable of loading 25 tons in an 8-hour bank-to-bank shift. Mr. Halbaum used the term "county average," and it occurred to him (Mr. Dean) when he read of the filler who loaded 25 tons (and it was assumed that he was not loading on to a conveyor) that Mr. Halbaum had omitted to relate the conversation which this man had with the checkweighman on the following day. It was very

* "Coal-mining in the State of Pennsylvania, United States of America," *Trans. Inst. M. E.*, 1914, vol. xlviii., page 367.

likely that the filler would be told that he had done something which was contrary to "county custom."

Mr. Halbaum knew, of course, the significance of these terms, "county custom," or "local custom," and that the reason why 10-cwt. tubs were used was partly to be sought in local custom. But did he know, when he spoke of high outputs per man at the face in thin seams, as high as or higher than the production per man in American 6-foot seams, that, instead of bolstering up the case for the 10-cwt. tub, he had simply ruined it? If the output at the face was so high, why was it that the output, for all men employed, was so low? It showed that thousands of men and boys were required to move those small tubs, backwards and forwards, between the coal-face and the pit-bottom, where, if tubs of larger capacity were used, hundreds could do the work and send the same quantity of coal to the surface.

Mr. Halbaum could imagine—and Mr. Carl Scholz also—how many "sea tubs" and men would be required, and how much time would be occupied, to move the live and dead "freight" across the Atlantic, in normal times, if cockle-boats were used instead of "Aquitanias" and "Olympics."

Mr. Scholz had made some interesting comparisons between the conditions prevalent in Germany and those in America, and had stated that it would be easier to adopt British cars in America than *vice versa*. There was no doubt about that: there would be ample room for 10-cwt. tubs in American mines, but Mr. W. R. Peck had explained what the result would be.

Mr. Scholz's mines were situated in Illinois, Indiana, and Oklahoma, where the United Mine Workers Association of America was in control, and the coal was shot from the solid with black powder—a reprehensible practice. In Oklahoma it was difficult to obtain shot-firers at 20s. a day for a few hours' work. He (the shot-firer) was like a man going down into the jaws of hell when he entered the mine to touch off the heavy charges after the other employees had gone home. At some Oklahoma mines all the shots were coupled up to electric wires, which were carried to the outside, and when the switch was thrown in they all went off together in the whole of the mine, like the simultaneous firing of massed batteries of field guns. Everyone was out of the mine when this took place, but the outside world did not know how many dust explosions and fires occurred.

In the State of Colorado—to make another comparison—where the United Mine Workers Association was not recognized, nothing but permissible explosives were allowed in the open-light coking-coal mines, and the coal must be undermined to a greater depth than the shot-hole.

Mr. Scholz had given a number of reasons why the output per man was higher in America than Europe. But he (Mr. Dean) was prepared to prove that, taking seams of similar thickness worked on the room-and-pillar or pillar-and-stall system, including only men employed in mining and filling and haulage work, America was in front of any other country, and the reason for this lay in the size of the mine-cars used.

Referring to the 6-foot seam, which the writer spoke of and by which he stated that an average output of 10 tons per man could be kept up easily if the men received a regular supply of empties, it might be of interest to add that the machine cut out 5 inches of slate, but there were three other bands of slate in the seam, and this slate was picked out by the fillers before they loaded the coal. This work took up a great deal of their time. Few of the fillers were what could be called "skilled" miners, and they were made up of the following nationalities:—

| | Per cent. |
|---|---|
| Austrians | 12 |
| Italians | 18 |
| Greeks | 22 |
| Bulgarians | 10 |
| Japanese | 8 |
| Mexicans | 30 |

In addition to cleaning the coal and loading it, they systematically cross-barred and timbered their working-places according to the State law, laid their own track, drilled their own shot-holes, and removed any roof slate which fell at the face. They worked 8 hours, and their earnings averaged 13s. 6d. per shift, although some of the men averaged 20s. (4·80 dollars) a shift. The earnings of some of the Mexicans often fell to 10s., because at the slightest opportunity a native of that country south of the Rio Grande would stop to roll and smoke a cigarette in an open-light mine. He was also fond of visiting if other men of his nationality were employed near him, and was a philosopher in a way, because he always looked to the future (mañana).

Mr. Halbaum had surmised that he (Mr. Dean) would not welcome a comparison of the results of British machine-mining with those of American machine and hand-work, but he was mistaken. Such a comparison would probably convert even Mr. Halbaum, and it was invited—showing outputs for all men employed. It would be interesting to see how the work of the ignorant agricultural emigrant from Eastern and Southern Europe compared with that of the "practical" miner now in the bondage of trade unionism.

He agreed, to use Mr. Halbaum's words, that safety was an essential condition of modernity, and the modern mining man in America realized that; but each State had its own mining law, and no two were alike. In addition, the State Mine Inspector was placed in office by the politician: the two worked hand in hand, and the high death-rate in American mines was a monument to that "combination." However, conditions were slowly changing for the better, and the future would see a much lower accident-rate. But large cars and locomotives were not the cause of numerous fatalities. Locomotives were used in Westphalia, and big trams in South Wales, and the accident-rates were not unduly high in those two coalfields. He could say, after 8½ years' experience in American mines, that the dangers of electricity were much exaggerated by labour politicians in Great Britain. There were hundreds of miles of mine roadways in America containing bare and insulated conductors, the bare wires being from 4 to 6 feet above the rail. One unaccustomed to such conditions would imagine that the roadways were exceptionally dangerous; but it was remarkable how quickly even a "greenhorn" learned that he must keep away from bare live wires. And, where the voltage was not over 250, men wearing ordinary cotton gloves frequently handled such wires.

In looking over the *Report of the Committee upon Mechanical Coal-cutting*, published by The North of England Institute of Mining and Mechanical Engineers, and the *Yellow Book No. 7*, issued by Messrs. Mavor & Coulson, Limited, of Glasgow, he was sorry to find that the figures given did not compare very favourably with Mr. Halbaum's 11 to 13 tons at the face in 3-foot seams. The following particulars were taken from the *Report of the Committee upon Mechanical Coal-cutting*:—

| Pages. | District. | Thickness of Seam. | Output per man at face. Machine-holing. | Output per man at face. Hand-holing. |
|---|---|---|---|---|
| | | Ft. Ins. | Tons. | Tons. |
| 34-35 | Scotland ... ... | 3 2 | 5 | — |
| 34-35 | Lancashire ... | 4 6 | 4 | 3 |
| 34-35 | Yorkshire ... ... | 5 5½ | 5·25 | 3·75 |
| 34-35 | Lancashire ... | 3 6 | 3·15 | 1·87 |
| 38-39 | Derbyshire ... | 6 6 | 4·5 | 3 |
| 40-41 | Warwickshire ... | 5 6 | 4 | 2 |
| 40-41 | Yorkshire ... .. | 4 4 | 3·6 | 3 |
| 40-41 | Staffordshire ... | 4 0 | 7·5 | 2·5 |

The following figures were from Messrs. Mavor & Coulson's *Yellow Book No. 7*, and related to machine-mining:—

| Page. | Thickness of Seam. | Output. |
|---|---|---|
| | Ft. Ins. | |
| 47 | 3 6 | Output to haulage per man per shift, 3·7 tons. |
| 54 | 5 2 | Coal filled per filler, 5 tons. |
| 66 | 5 2 | Output to haulage per man per shift, 5½ tons. |
| 75* | 1 9 | Coal filled per filler, 4 tons. |
| 78† | 1 6½ | ,, ,, ,, 8 to 9 tons. |
| 89 | 4 3 | ,, ,, ,, 4 tons. |

* A Belgian colliery. † A Continental colliery.

Mr. Halbaum had criticized what he considered the inefficiency of machine-mining in America, and had spoken of machines "eating their heads off," and of methods which would cause the bankruptcy of British collieries. It was not necessary to explain to members possessed of a liberal knowledge of machine-mining that the time consumed in flitting (room-and-pillar work), unloading and loading the machine, pulling up to and back from the face, oiling, changing bits, clearing small falls, removing and resetting props, etc. (a dataller was not provided to do this work), was much in excess of that required to cut across the places. When the machines were actually cutting, the speeds per minute were those stated in the tables. The lineal cuts per shift were not by any means record figures, and, if they were below British averages, he (Mr. Dean) was glad to know it. Comparisons were not odious: this was a platitude often used by persons who did not understand its meaning. A comparison was of practical utility: it served to ascertain the true relation of objects. Odious signified hateful, and he felt sure that hate did not exist in the minds of the writer of the paper or of the gentlemen who had taken part in the discussion.

On the contrary, the desire was to aid and assist. A man could only gain from the experience of others by making comparisons.

The writer wished to thank heartily all the gentlemen who had taken part in the discussion. His object in writing the paper was not to make comparisons unfavourable to Great Britain; he had something much larger in view, and he appealed to young British mining men, when they went abroad to India, China, South America, Africa, and other countries, not to take their 10-cwt. tubs and narrow gauges with them.

Just as the timid men of to-day eclipsed the still more timid men of 30 years ago, so would the men of to-day be eclipsed in their turn by their bolder sons, who would presently increase output and profits by the simple means of doing all the "inept" and "unpractical" things which their fathers labelled impossible. The fruits then reaped would justify the comparisons that were now being made.

Mr. SIMON TATE (Trimdon Grange) wrote that the members were much indebted to Mr. Dean for his very interesting and instructive paper. In offering the following observations, he would like it to be understood that he did so, not in a spirit of captious criticism, but for the purpose of stimulating a full and exhaustive discussion, to elicit further information, and to ascertain whether it were possible to adopt all or any of the suggestions set forth in the paper, with the view of improving the output of British collieries, the production of the workmen engaged therein, and of lessening the cost of working.

The subjects dealt with by Mr. Dean were familiar to all the members, and the question of reducing the cost of working coal was one that was daily before every colliery manager, engineer, and agent. It was one of the principal ideas set forth in the Inaugural Address of the first President of the Institute at the first meeting, when he stated that one of the purposes of the Institute was that of advancement in the science of mining and the economical working of coal. Personally, he considered that this was the main object which ought ever to be before the eyes of mining engineers, especially those who were members of this Institute.

The writer of the paper had adduced statistics to prove that the American methods of producing coal were more efficient in

obtaining a large output per man than were the methods adopted in other countries. When he stated that the annual output per man employed in the bituminous mines of the United States had been raised in 23 years from 579 to 837 tons, equal to an increase of 44 per cent., the result was so startling that British mining men were bound to investigate the reasons, and to ascertain whether it was possible for them to adopt such of the American methods as were applicable to the conditions prevailing in British mines. Mr. Dean had given altogether four principal reasons for their success, namely:—

(1) The use of large-sized mine-cars, rendered possible by the adoption of loose wheels and axles.

(2) The use of coal-mining machines, generally electrically driven.

(3) The use of electric and compressed-air locomotives for underground haulage.

(4) The provision of strong, heavy underground railroads, properly engineered, correctly aligned and graded, well and substantially laid throughout.

(1) Mr. Dean gave it as his mature opinion that the principal reason why the United States was so far ahead in the output per man was due to the use of large-capacity mine-cars. This was an important assertion, probably the most important in the whole of his paper.

Probably no one would question the correctness of the theory that it was advisable that the capacity of the vehicle used for carrying coal or similar material should be as large as practicable, and that the net weight of such a vehicle should be as small as possible, compatible with sufficient strength to stand wear and tear: for, all other factors being equal, the greater the difference was between the load carried and the tare of the vehicle, the greater would be the useful effect obtained.

It appeared to him (Mr. Tate) that the benefit of using large cars was cumulative, for every time that the car, whether laden or otherwise, was moved by man, horse, or mechanical means, a proportionate gain accrued.

He was strongly of opinion that in the North of England tubs of too small a capacity were often used, and that in many cases larger tubs, following somewhat American ideas, would be an advantage. If the American car carrying 4 tons was com-

pared with the English tub carrying 10 cwts., it would be found that for the same load of 4 tons the following result would be obtained:—

| 1 AMERICAN CAR. | Pounds. | 8 ENGLISH TUBS. | Pounds. |
|---|---|---|---|
| Weight of one empty car ... | 3,000 | Weight of eight empty tubs (6 cwts. each) ... ... | 5,376 |
| Load of 4 tons carried ... ... | 8,960 | Load of 10 cwts. per tub ... | 8,960 |
| Total weight of one loaded car | 11,960 | Total weight of eight loaded tubs | 14,336 |

This was equal to 20 per cent. less weight to draw on the full tub, and 79 per cent. on the empty tub, every time that the tub had to be forcibly moved, and further, each time that the large car was in service it was eight times as effective as one 10-cwt. tub.

In Northumberland and Durham the weight of coal carried in a tub was not quite as 2 to 1; in fact, sometimes with very small tubs it was as low as 1½ to 1. In America with the big tubs it was as 3 to 1, which was 50 per cent. better than British ordinary practice.

Moreover, there was in the one case only the friction of four large-sized wheels to overcome, as against thirty-two small wheels in the other case; and, taking into consideration the fact that the one had roller-bearings with a minimum amount of friction, and that in the other there were thirty-two wheels with bearings generally of a very crude character, the difference in favour of the larger tub must be enormous.

In the case of a train of twenty of these tubs, which would be equal to a train of 160 of the British small tubs, the drawing power required to haul the train would probably not be more than half that required to haul the train of small tubs.

Mr. Dean had mentioned especially the advantage of the large tub in keeping the fillers fully employed, and had stated that these men filled about 15 tons per shift of 8 hours. Whilst not wishing to belittle this statement, he (Mr. Tate) would like to mention that he had, during the last 30 years, some putters and fillers filling and putting, from a seam averaging 2 feet 3 inches thick, 10 to 12 tons per shift, using small tubs of a capacity of 7½ cwts., and putting the tubs an average distance of about 70 to 80 yards. This arrangement of labour had the following advantages:—(*a*) constant employment; (*b*) change of work

almost equal to a rest; and (*c*) no waste of labour in changing "led" tubs. The putter in most cases could reach the flat sooner than he could change the tub, for it must be remembered that every time that a putter changed a tub he travelled the distance between the siding and the face four times—twice with a tub and twice without one; in fact, all his exertions in changing the tub were directly and positively wasteful.

This system of filling and putting was, in his opinion, better than keeping a filler constantly employed at the face at one class of work, because the work was not so monotonous, the filler had a necessary change of work and position, and, instead of sitting down to rest, he received to some extent the rest that he needed by the change of labour; if ordinary care were taken to maintain a supply of tubs, the work of the putters and fillers was practically continuous from start to finish of the shift. He (Mr. Tate) considered that it was bad practice to have a long distance between the flat and the face.

When Mr. Dean gave it as his deliberate opinion that the large increase in the output per person employed in American mines was principally due to the adoption of tubs carrying 4 tons of coal, he (Mr. Tate) was somewhat sceptical. He could realize that in thick seams or in longwall working, where conveyors were in use under suitable conditions as to the inclination of the seam, etc., such tubs could be favourably used; but he could not imagine such manifold results as did Mr. Dean. For, after all, it was principally a question of getting a hewer's or a filler's work out, and if he was supplied with an unlimited number of 10-cwt. tubs, this was equal to (or better than) being supplied with a full quantity of 4-ton tubs. In British seams and under British conditions, one could never hope to approach tubs of a capacity of 4 tons.

He thought that if he had to lay out a new pit he would certainly endeavour to adopt to some extent the American idea of providing a considerably larger tub than was generally used in Britain. He had no doubt that a tub built on the American principle, to carry 15 or 20 cwts., with loose wheels and roller-bearings, would be as light and as easy to move as the present ordinary tubs, and would travel in less height and therefore save making height.

He need hardly say that the larger size of American car could

not readily be adopted at the old collieries; in fact, in order to get room in a shaft for two cages sufficiently large for some of the cars, a circular shaft 22 feet in diameter would be required. Such a change might possibly be effected in some of the shallow pits, but in deep pits it would be too great an undertaking.

(2) The writer had mentioned the extensive use of coal-cutting machines, and here he (Mr. Tate) thought that he was on safe ground, because in these days of restricted physical effort he believed that mechanical coal-cutters were absolutely essential wherever the work of coal-getting at the face was at all laborious. It mattered not whether the seam was thick or thin, holing by manual labour in strong material was fast becoming impracticable.

In this country the passing of the Minimum Wage Act had been the death-knell to strenuous coal-hewing, the great majority of coal-hewers preferring to earn the minimum standard wage on easy terms to earning a moderately good wage for which they had to work laboriously; and in future it would be necessary that the coal-getting must be made easy work, either by altering the method or the system of work, or by installing machinery to do the strenuous part of the coal-hewer's duty.

American mining engineers seemed to be far ahead of their British brethren in machine-mining. Mr. Dean had stated that one electrically-driven Arcwall machine had cut in one shift of 10 hours twenty rooms each 20 feet wide with a depth of holing of 7 feet. This was equal to an area of 311 square yards, and with a seam, say, 3 feet thick, one machine would yield about 220 to 250 tons of coal. It seemed more like a fairy tale than honest coal-mining, and yet the statement was further verified by the number of fillers allotted to each machine. Surely, with such facts before them, it was time for British mining engineers to alter their ways and methods.

The North of England was the home of bord-and-pillar working, which system seemed particularly adapted to the American method with machines, and in "whole-mine" working it would be possible in many cases to use electricity with perfect immunity from danger, whereas in longwall working in the same seam it might be considered highly risky.

At the present time, owing to the scarcity of hewers and stonemen, it was of vital importance that strong efforts should

be made to use machines wherever possible, in order to maintain the output; and, as it was necessary that as few hands as possible should be employed in stone-work and shift-work, it was advisable to work the coal into pillars by coal-cutting machines wherever the coal was hard. The writer had not mentioned the use of power-drills, which were useful and labour-saving machines when used either in coal or in stone.

It should be borne in mind that, owing to the war, it might be many years before the full complement of men returned to the mine; and, as it was of the utmost importance to obtain as large an output of coal as possible, it was one's duty to introduce machinery wherever possible to take the place of human labour, and especially so for all such laborious work as coal-hewing in hard seams.

He (Mr. Tate) had recently installed some compressed-air pick-machines and power-drills, and found that by their use he could materially increase the output per man; but, owing to the obstructive tactics of the workmen, the benefit in costs which he ought to have received had been much discounted.

(3) In the free use of electricity American mining engineers had undoubtedly a great advantage over their British brethren, as they were not fettered by stringent and restrictive electrical laws such as were in force in Great Britain; consequently, they were able to take full advantage of its adaptability and cheapness for all their manifold mechanical requirements. They could use trolley-locomotives, and self-propelling coal-cutting machinery which travelled from place to place under its own power; in fact, for all purposes where steam or compressed air would otherwise be applied they used electricity. No one could appraise the full value of this freedom and liberty to the mining engineer in adapting and using self-propelling electric machinery for such purposes as coal-cutting, and locomotive haulers for conveying the coal from the working-face to the surface.

If the electrical restrictions at present imposed upon British mining engineers could be relaxed and altered so as to give greater facilities for its use wherever safe, it would doubtless greatly facilitate the coal output, and do more material good than 50 per cent. of the enactments that had during recent years been placed on the statute books; and in some measure it would

make up for the loss of output which had resulted, and would continue to result after the war, owing to so large a number of men having joined the forces.

The American legislators evidently did not wish to hamper their mining industry with all sorts of mischievous and grandmotherly legislation such as was recommended in this country by popularity-hunting members of Parliament and amateur mining experts, who were unfortunately supported by political aspirants. If only they would be content to confine their great powers for mischief to sanitary measures and the proper distribution of sanitary pails, etc., instead of meddling with all sorts of technical subjects, it would be better for the coal-trade and the country generally.

(4) Owing to the use of heavy cars in the United States, it followed as an absolute necessity that there should be good railroads. But he questioned whether American practice was very much ahead of British practice, except as to the strength of the rails used, which, of course, was simply a question of the proportionate strength of the rail to the load drawn; in fact, he questioned whether in America the strength of the rails in proportion to the load was any better than in Great Britain. Further, he doubted whether the speed of their trains was anything like what it was in some of the pits in this country. He considered that in the matter of good haulage-roads many British collieries would not be easily excelled. At some pits the trains were travelling at about 20 miles an hour, and this fact alone proved the excellence of the engine-roads. He considered, therefore, that it was not in this branch of equipment that British mines fell short.

He was afraid that the disability that existed in Northumberland and Durham to compete with America in the output per person employed was almost beyond the power of the mining engineer to overcome entirely, as the physical conditions of these coalfields were unfavourable, inasmuch as they were now practically fully exploited, and in many cases very thin seams were being worked. It was not uncommon in the west of the County of Durham to work seams 20 inches thick, and in some cases as thin as 18 inches.

There were other factors which operated against coal-mining in Great Britain, such as stringent Acts of Parliament, all tend-

ing to have a detrimental effect upon the output, costs, etc.; trade-unionism with all its restrictive influences; old customs; restrictions of employment of both young and old; short hours of labour; too many holidays, including the fortnightly pay Saturday; in fact, the restrictions were almost innumerable, and many of them were practically insurmountable. It was not only America which was leaving the Mother Country so far behind, but even her Colonies were forging ahead.

It was well known to all mining engineers that the restrictive influences previously mentioned had a serious detrimental effect upon the output per person employed, and although it was quite impossible for the writer to apportion the due amount to any of the individual adverse influences at work, yet when it was found that the output per person employed in mining in this country was sinking continuously, it became imperative that the matter should receive careful attention, and, if possible, that means should be devised to remedy the defects. He appended in Table I. some comparative figures bearing upon this question which were strikingly ominous:—

TABLE I.—TONS OF COAL PRODUCED PER ANNUM PER PERSON EMPLOYED IN VARIOUS COUNTRIES.

| Period. | United Kingdom. | United States. | Australia. | New Zealand. | Canada. |
|---|---|---|---|---|---|
| 1886-1890 ... ... | 312 | 400 | 333 | 359 | 341 |
| 1906-1910 ... ... | 275 | 596 | 462 | 470 | 439 |
| 1911 ... ... | 260 | 613 | 485 | 487 | 395 |
| 1912 ... ... | 244* | 660 | 542 | 503 | 472 |
| Increase per cent. | — | 65 | 63 | 40 | 38 |
| Decrease per cent. | 17† | — | — | — | — |

* Strike year. † Calculated from 1886 to 1911.

It would be observed that the output of the United Kingdom was steadily decreasing, and, even omitting the year 1912, which was the great strike year, the output had fallen 17 per cent. from 1886 to 1911; in America the output had increased 65 per cent. from 1886 to 1912; whilst that of the Colonies mentioned in the table had also gone up 63, 40, and 38 per cent. respectively.

Naturally, if there was a restricted supply of any article of general use the first effect of the shortage was to enhance the price of the article. This was clearly shown in the case of coal, for, while the output per person employed had lessened, the price

or value per ton at the pit-mouth had increased, so that there was probably the same margin of profit at the best collieries, where the labour cost bore a smaller proportion to the total cost; but this was not the case at those collieries where thin, hard, and difficult seams had to be worked. The effect of the reduced output at these latter collieries had been serious, and had resulted in the stoppage of many such pits.

The high cost of coal had a baneful and far-reaching effect on the manufacturing trade, and it probably accounted for the slow advancement in iron-production, which for many years had been practically stagnant: for, whereas is the year 1865 Great Britain made five times as much iron as Germany, Germany had passed us in 1910, and made 50 per cent. more than we did. In the production of steel we were still further behind. Table II. showed the production of iron and steel in Germany and the United Kingdom.

TABLE II.—PRODUCTION OF IRON AND STEEL IN GERMANY AND THE UNITED KINGDOM.

| Year. | Iron production. | | Steel production. | |
|---|---|---|---|---|
| | Germany. | United Kingdom. | Germany. | United Kingdom. |
| | Tons. | Tons. | Tons. | Tons. |
| 1865 ... | 975,000 | 4,896,000 | 100,000 | 225,000 |
| 1870 ... | 1,391,000 | 6,060,000 | 170,000 | 287,000 |
| 1875 ... | 2,029,000 | 6,432,000 | 347,000 | 724,000 |
| 1880 .. | 2,729,000 | 7,802,000 | 624,000 | 1,321,000 |
| 1885 ... | 3,687,000 | 7,369,000 | 894,000 | 2,020,000 |
| 1890 ... | 4,658,000 | 8,033,000 | 1,614,000 | 3,637,000 |
| 1895 ... | 5,465,000 | 7,827,000 | 2,830,000 | 3,312,000 |
| 1900 ... | 8,521,000 | 9,052,000 | 6,646,000 | 5,130,000 |
| 1905 ... | 10,988,000 | 9,746,000 | 10,067,000 | 5,984,000 |
| 1910 ... | 14,793,000 | 10,380,000 | 13,699,000 | 6,107,000 |

Mining engineers could, however, excuse themselves to a certain extent, because he found that in other industries the United Kingdom was behind America to a similar extent. In about twenty-six trades he found that the production per worker per week was from two to three times more in America than in Great Britain.

Why was this country being left so far behind? In the lifetime of several of the present members of the Institute the United Kingdom had produced more coal than all the rest of the world combined; in fact, in the year 1845 she produced twice as much. Now she was only second in the race.

In his opinion there were three principal causes for this backwardness. First, the coal-owner had often been too conservative in his ideas of business, too indifferent to the changes which had been gradually taking place in the labour world, and also to his dual interests in the working man's good offices, namely, his labour and his vote. Secondly, politicians of both parties desiring to obtain votes had increasingly flattered both masters and men, and, instead of preventing the workers from reducing their output to a minimum, had actually encouraged them in that suicidal policy by restrictive legislation. By striving after popularity and votes, and by passing pernicious laws, the politicians had encouraged idling on the part of the workmen, with the result that this country had fallen much more rapidly than she ought to have done from her position as the premier coal-producing country to a secondary position. At the present rate of decline in the output per man it would be found that Great Britain would be handicapped as the supplier of the markets of the world, and that other countries would obtain her position as the greatest trading nation. Thirdly, there was the restrictive policy of the trade unions. During the last fifty years great improvement had taken place in all kinds of mining machinery for increasing the output and reducing the more laborious part of coal-mining, and great economy was expected to follow; but unfortunately the whole benefit expected had been nullified and absorbed by the policy of trade unions. These bodies by every means in their power, assisted by legislation, had endeavoured to restrict the output per man, not always by the bald system of ordering a member to do only a certain "stint" of work, but rather by limiting his opportunities for producing his maximum duty, by limiting his hours of labour, by taking away the incentive to put forth his best efforts when difficulty arose, and generally by obtaining a greater payment than was warranted for his labour, a payment much higher than that made for similar duties performed by other labouring classes. The result was that British coal-miners had succeeded in reducing the output of coal per man and in creating an artificial scarcity with spuriously augmented prices, which must have a detrimental effect on our manufacturing industries, and would some day result in a reduced demand for both our manufactured goods and for our coal and iron.

He was fully aware that at the present time the British coal-trade as regarded prices was in a flourishing condition. The only great drawback was the shortage of labour; consequently the necessary incentive existed for mechanical improvements, so as to help to meet the present abnormal demands, and also to educate mining engineers and workmen alike in the use of such machinery as would enable us to improve both our present and future output.

In the present abnormal state of the coal-trade in this country coal must be produced at any cost; in fact, even if it were at some loss it was imperative that as large an output as possible should be produced. He thought it would be found that for the current year the output per person employed would be considerably increased, owing, not to any extra effort on the part of the miner, but rather to the shortening of hands, the stoppage of all exploring work or extensions, and, to a considerable extent, to the stoppage of the less favourable portions of our mines.

The great difference in the methods practised in America and in Great Britain seemed to be that in America the wages paid were in proportion to the output, whereas in Great Britain they were in proportion to the selling price. The result was that in America every effort was put forth to obtain a big output cheaply, whilst in Great Britain enhanced wages had to be paid because of restricted supply. In other words, in America the harder the men worked the higher were their wages, whilst in Great Britain the smaller the output was the higher were the wages.

He would like to mention that in the compilation of the data and figures in his remarks he was much indebted to an article by Mr. J. Ellis Barker in the *Nineteenth Century and After*.*

Mr. E. O. Forster Brown (London) wrote that the questions raised in the paper and in the subsequent discussion could not fail to be of great benefit when problems of mine haulage and coal-cutting were being considered, especially in the case of new coalfields.

He could not agree with Mr. Dean's opinion that the principal reason why the United States led in production per man was because mine-trams of large capacity were used, as com-

* 1915, vol. lxxviii., page 1233.

pared with those in use at German, Belgian, French, and British mines. The principal reason why the United States led in production per man was, in his opinion, because a greater proportion of the coal worked in that country was obtained from thick seams with good roofs, lying at comparatively shallow depths and at a slight inclination, and because of the few restrictions against taking electricity up to the coal-face. The use of large trams undoubtedly enabled better advantage to be taken of such natural conditions than would be the case if small trams were employed, but this feature could hardly be claimed as the principal reason why the output per man was high.

A point which did not appear to have been raised in discussing the relative merits of large and small trams in the two countries was that, while in this country and on the Continent collieries were usually laid out with a view to eventually working several seams of varying thickness, so that the trams had to be designed to fit the thinnest seam as well as the thickest, in the United States it was far more common to find collieries laid out to develop one seam only. To cite cases from personal experience, he might mention the Pittsburgh Seam, from 4 to 6 feet thick; the Connelsville Seam in the Pennsylvania coalfield, varying from 7 to 10 feet in thickness; and the Big Vein in the Georges Creek coalfield, 12 feet thick. A large number of collieries were laid out to work these seams alone, and, in view of the strong competition, it was improbable that they could afford to work seams of inferior thickness or with less favourable natural conditions, even when such existed in the same property —at any rate, not until the thicker seams mentioned were to a large extent exhausted.

Theoretically, where the natural conditions permitted, the case for large trams would appear to be a very strong one. A question on which further information would be valuable, however, was as to the best means of handling large trams between the main haulage-roads and the face. His experience was that it was a comparativly easy matter to form an opinion on the expense justified in making and in maintaining a good main haulage-road to handle a large tonnage; the difficulty was to determine how much it was worth while spending on secondary haulage-roads in order to keep and maintain a good road and track in view of their temporary character. As a rule, secondary haul-

age cost a great deal more per ton than main haulage, although the distances to be traversed by the former were very much less, while derailments occurred much more frequently. With larger trams, for the same quantity of coal handled as by small trams, more money must be spent on secondary haulage-tracks and curves in order to avoid derailments and excessive friction. The adoption of trams beyond a certain size, except in very flat seams, would appear to eliminate the question of horse, mule, or manual haulage on the secondary roads; and where electricity could not be used near the face, the choice would appear to lie between secondary rope or compressed-air locomotive haulage. Information on the application and cost of these or other similar systems in the United States, and the measure of success which had attended them, would be useful.

He could confirm from personal experience the care taken in laying and keeping in good condition the main haulage-tracks at American collieries. These often compared favourably with standard-gauge tracks kept by some of the railway companies in that country.

Mr. SAMUEL HARE (Bishop Auckland) said that Mr. Tate appeared to agree with the writer of the paper that the labour-saving machines—especially coal-cutting machines—in America were responsible to a large extent for the larger output per man as compared with England. He also gathered that Mr. Tate did not think that English mining engineers had done as much as American mining engineers in adopting labour-saving machinery. For some years past he (Mr. Hare) had been watching American mining, and had admired the ability of American mining engineers in overcoming the difficulties in connexion with labour by developing machine-mining. He had tried their very latest machines, and he believed that he had had at one of his collieries the best American operator—at least, he was said to be—sent to demonstrate to them what an American machine could do when operated by an American, but the experiment had been an absolute failure. This expert operator could not do any better than their own men, and the particular machine gave no better results than they were already achieving, so that the experiment had to be abandoned.

He thought that most of them would agree that English long-wall coal-cutting machines were as good as the American

machines. He had used both kinds, and, whilst he could not praise too highly the best American longwall machine, he believed that longwall machines were being produced in this country which were equally as good. In the case, however, of bord-and-pillar working, the conditions were different. They had only to look at the illustrations in the paper to see the different conditions under which the American machines worked. In a vast space there was hardly a stick of timber, a condition which was absolutely impossible in England. Owing to the bad roofs, they had to timber nearly up to the face, and, in addition, they had to contend with the Government regulations, so that it was practically impossible to use the American bord-and-pillar machines in an ordinary English pit.

Then there was the question of depth. He could not imagine pits of the average depth of English mines being worked with the small amount of timber that was used in America, and he took it that the coal-cutting was done at very limited depths.

He had tried rails weighing 70 pounds to the yard, in order to get the machines transferred quickly from place to place; but, although he had employed American operators, it was found impossible under English conditions to do this. A very important matter with regard to coal-cutting machinery in connexion with bord-and-pillar working was the fact that it was absolutely necessary, in order to get these machines moved quickly from place to place, that naked wires should be used. This was contrary to the Government regulations in Great Britain, and he would be sorry indeed to adopt this practice, even if it were allowed.

He thought that no comparison could be made between the working conditions in the two countries, and it would be very unfair to charge English mining engineers with being behind American mining engineers in up-to-date practice. He was perfectly certain that if they had anything like the same conditions as those obtaining in America, they had in England mining engineers who fully realized the advantages to be gained by a more extended use of machinery in connexion with mining, and who possessed the necessary ability required to design and instal it.

He agreed with Mr. Tate in other respects, and congratulated him on the excellence of his criticism of the paper.

Mr. JOHN H. MERIVALE (Broomhill) said that he was inclined to agree that the principal reason for the larger output in America was due to the conditions there, namely, the thicker seams and better roofs. At the same time, there were many important points to which attention had been drawn by Mr. Dean and emphasized by Mr. Tate which they might very fairly consider. First, there was the question of larger tubs. There was no doubt that if a larger tub could be used it would be an immense benefit, although he was not prepared to say that a larger tub could be used in very many cases. There was a point in connexion with tubs which had not occurred to him until looking at a copy of the *Nineteenth Century and After** he was surprised to find it stated, according to Board-of-Trade figures, that only ½ per cent. of the life of a railway-wagon was employed usefully, and for the remaining 99½ per cent. of its life it was standing about or running empty. He thought that they would find that only about 3 per cent. of the life of a tub was employed usefully—that is, running full. If that was so, anything which would enable them to get more work out of their tubs by increasing the beneficial load and decreasing the dead load, as in the case of a larger tub, would be an advantage.

There was no doubt that they did not use machinery as much as they might, nor as much as was done in America. This was not entirely due to the different conditions of working, but to a great extent to difficulties experienced with the workmen. Before new machinery could be introduced to supersede manual labour, arrangements had to be made with the men, and very properly so in his (Mr. Merivale's) opinion; but difficulties were always raised, and when the workmen were requested to give reasons for their objections, the general reply was that the new machinery was an innovation. "It had never been done before" was a stock answer. The men would not do anything that their grandfathers had not done before them. He thought that matters would be greatly changed after the war in that respect. There would be a shortage of men, and owners would be bound to use more machinery than they were doing at present. There was an idea simmering in the minds of scientists, which, if it came to fruition, would be of great advantage, namely, the transmission of power by wave motion. Mr. Tate

* 1916, vol. lxxix., page 470.

had drawn attention to the fact that they were hampered by Government regulations which restricted the use of electricity. In many ways those regulations were wise, as undoubtedly electricity had its dangers. If, however, they could get a substitute, if they could get power conveyed by means of liquid waves, they would have a means of transmitting power to their coal-cutting machines which was simpler, fool-proof in fact, and at the same time it was incapable of doing damage by causing an explosion. It was absolutely safe.

Finally, there was the other point to which Mr. Tate had drawn attention, namely, their method of regulating wages, and he thought that they hardly realized how insane that method was. They paid their men according to the selling price of the product; in so many words they said: "Produce as little coal as you can; it will raise the price and put up your wages." He (Mr. Merivale) objected to this arrangement. Whilst admitting that it was a great advance upon former methods for the regulation of wages, he thought that the time had now arrived when it should be superseded and wages be based on the difference between the selling price and the cost. There would be no more difficulty in arranging a sliding scale on that basis than there was in arranging a sliding scale on the selling price. He looked forward to the day when that method would be adopted, and the effect of it would be to induce men to produce as much as they possibly could, and at as low a price as they could. They would then have a direct interest in making the mine a success, to the benefit of themselves, the coal-owners, and the country.

The PRESIDENT (Mr. T. Y. Greener) said that Mr. Tate had given them much food for thought. He had not gathered that Mr. Tate was casting any reflection on the British mining engineers, but rather thought that he was emphasizing the fact that the reasons why the outputs in America were larger than in this country were that the conditions were very much better, there was less legislative interference, trades unions did not restrict the output to the same extent as in Great Britain, and last, but not least, the method of payment was better.

Mr. SIMON TATE said that when the paper was read he thought that it had been somewhat overlooked by the mining engineers

in the North of England, and that there were points in it well worthy of their attention. The object of his remarks had been to call their attention to these points, and he thought that his remarks had met with so much approbation from the members that his purpose had been fully realized. He would, however, be pleased to discuss the matter further at the next meeting.

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Mr. Hiram H. Hirsch's paper on "The Hirsch Portable Electric Lamp" was taken as read, as follows:—

# THE HIRSCH PORTABLE ELECTRIC LAMP.

By HIRAM H. HIRSCH.

*Introduction.*—The writer has pleasure in submitting a short description of the Hirsch lamp,* which, though largely used in the United States of America, has not yet been adopted in Great Britain.

The lamps, which consist of (1) the watchman's lamp and (2) the miner's lamp, are portable, and have been designed to provide a safe and reliable light for use by watchmen, and in mines, rescue-work, powder-works, oil-refineries, and other places where special precautions become necessary on account of the presence of explosive materials or gases. The lamps are in each instance operated by a storage-battery contained within a casing, and this supplies the current necessary for a miniature incandescent lamp. Each safety-lamp forms a complete unit, and can be carried from place to place or held in any position.

(1) *Miner's or Watchman's Hand-lamp* (Fig. 1).—This lamp consists of a storage-battery placed on an asbestos cushion in a cast-aluminium casing provided with a hinged top. The top piece is also of cast-aluminium, and is provided with a hook, a reflector, and terminals for making contact with both poles of the battery. The reflector unit consists of concentric safety shells, an incandescent lamp, a safety glass, a crystal, and a switch.

*Battery.*—The battery consists of two horizontal lead plates, each about an inch thick, placed in the bottom of a hard-rubber jar and separated by wood and perforated hard rubber, the bottom plate being positive. The positive and negative leads extending from the battery plates are enclosed in glass tubing. The solidified electrolyte consists of a gelatinous substance developed by the manufacturers. The battery is supplied with a vent-plug, and the top of the battery is sealed

* See *Trans. Inst. M. E.*, 1915, vol. xlviii., page 384.

with an insulating compound. Both the negative and the positive terminals consist of antimonious lead.

*Casing.*—The casing for the battery is made of cast aluminium about $\frac{1}{8}$ inch thick. It is open at the top, the top edges being provided with tapered or bevelled edges. A magnetic spring lock is housed in on the bottom casing, and a soft rubber cushion is placed in the bottom.

FIG. 1.—MINER'S OR WATCHMAN'S HAND-LAMP.

*Cover.* — The combined cover with reflector-holder is made of cast-aluminium about $\frac{1}{8}$ inch thick. The sides are provided with bevelled or tapered edges to fit to the bottom casing, and a hook is attached to the top of the reflector casting. One end is drilled and tapped for a screw, the end of which fits into a clearance hole in the casing and secures the two parts in place. Spring-clip contacts are insulated and secured to the underside of the cover, and make contact with both terminals of the battery; it is connected by a short length of insulated wire to the central contact-screw of the miniature lamp-socket.

*Reflector.*—The reflector is constructed with three concentric shells, the intermediate shell being insulated from the other two and connected to the negative pole, and the other two shells to the positive pole of the battery. The distance between these shells varies at different points from $\frac{1}{32}$ to $\frac{1}{4}$ inch. The shells are so arranged that if

the reflector should be crushed or punctured, the current to the lamp is cut off by the shells being short-circuited between the battery and the lamp before the lamp-bulb can be broken. The inner shell is fastened to the screw-shell of the lamp-socket, and the intermediate shell is fastened under the central contact of the lamp-socket. A brass screw passes through an insulating bushing in the back of the top piece, threads through a square brass nut, then through an insulating cylinder, and into a brass hexagonal nut forming the centre contact of the lamp-socket. A contact spring, clamped under the square nut, but insulated from it and making contact with the top piece, projects outward and makes contact with the outer shell of the reflector. The outer end of the reflector shell is provided with a thread to receive a ring that secures a convex crystal approximately $\frac{1}{8}$ inch thick against a soft rubber jacket.

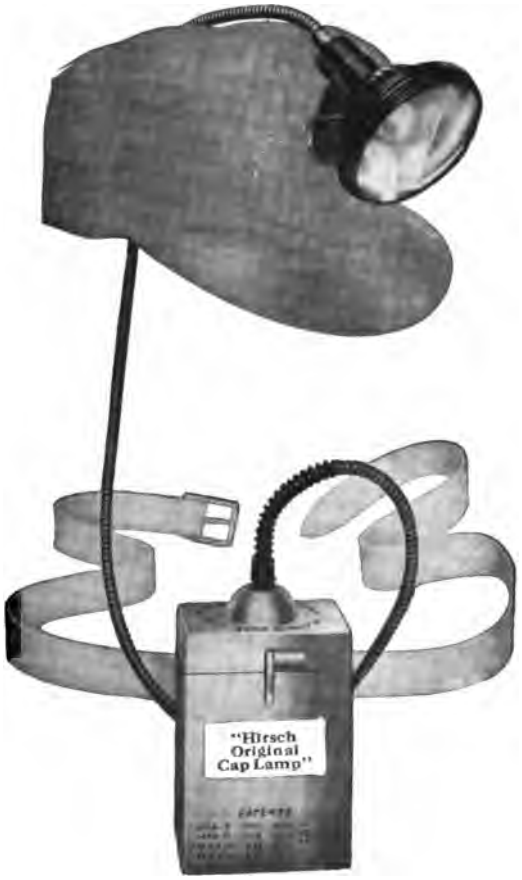


FIG. 2. MINER'S CAP-LAMP.

*Lamp-bulb.*—The incandescent lamp used is of the 2-volt 0·55-ampere tungsten-filament type, with a miniature lamp-base.

*Safety-glass.*—The safety-glass consists of a piece of window glass $2\frac{3}{16}$ inches long, 1 inch wide, and about 0·05 inch thick, supported across the reflector-shell back of the crystal.

*Switch.*—The switch on the watchman's lantern consists of a screw-switch fastened to the outer case of the reflector and a knurled-head screw, which threads through the outer shell and makes contact with the spring. The tension of the spring is such that it presses against the contact-spring in the corner of the battery-case.

(2) *Miner's Lamp* (Fig. 2).—This lamp consists of a storage-battery placed in a cast-aluminium box designed for mounting on the miner's belt. The box is supplied with a handle, and contains the necessary contact-springs for making contact with the battery-terminals. Through the upper part of the box the armoured cord extends. The other end of the armoured cord is fastened to the headpiece. This headpiece is similar in construction to the reflector of the watchman's lamp, and consists of an incandescent lamp, a reflector, safety-shells, a safety-glass, a crystal, and a switch.

*Battery.*—The battery is of the same construction as that of the watchman's lamp.

*Casing.*—The casing for the battery consists of a cast-aluminium case about ⅛ inch thick, made with a detachable hinged cover to lock to the bottom of the case. The top is provided with a wire handle, and on the back is an opening through which the miner's belt passes. Two copper springs insulated and fastened to the top of the case make contact with the negative and positive terminals of the battery.

*Headpiece.*—The reflector, which is used as a headpiece, is of the same construction as the reflector provided for the watchman's lamp, except that the central contact for the miniature receptacle consists of a hexagonally-headed screw, which passes through an insulating cylinder and threads into a nut. This nut forms the central contact of the inner insulated wire, which is on the inside of the armoured cord. The inner wire is negative.

*Lamp-bulb.*—The incandescent lamp used is the same as watchman's lamp.

*Armoured Cord.*—The cord consists of a single piece of flexible single-braid rubber-covered wire, made up of seven strands of No. 30 B-and-S-gauge copper wire. The outer armour

sists of a single strip of formed brass, which overlaps and locks itself between succeeding turns of the strip, and is known as a flexible brass tubing.

The weight of the lamp complete is 3¼ pounds, and of the battery only 1⅞ pounds.

*Advantages.*—The following claims are made for both the lamps:—

(*a*) The storage-batteries are easily and quickly handled in charging, easy to take apart and repair when necessary, and all parts are quickly accessible.

(*b*) The sediment that tends to loosen from the positive or bottom plate still remains part of the plate.

(*c*) The jarring or upsetting of the battery will not affect the plates as in the batteries having thin vertical plates. Short-circuit of the battery will not injure the plates.

(*d*) The battery will not upon short-circuit arc sufficiently to ignite gas, black powder, guncotton, cartridge powder, alcohol, or other vapours. Immediately on short-circuit the voltage drops to zero, on account of the peculiar characteristics of the battery plates.

The above statements are made as the result of tests carried out at the Frankford Arsenal and at the Drexel Institute, Philadelphia.

The solidified electrolyte always remains in contact with the plates, no matter how it is handled, whether upside down or not, and when in any position will not ruin a man's clothes by the spilling of electrolyte.

The batteries will give an average light of 5 candle-power for 12 hours or more on each charge.

If the crystal and safety-glass should get broken in an explosive atmosphere, the lamp is extinguished by the safety-glass opening the circuit at the switch and thereby eliminating the [illegible] igniting anything explosive on account of breakage of [illegible]amp-bulb. The lamp becomes extinguished before the [illegible]reaks.

[illegible] arrangement of the three shells in the reflector or head-[illegible]ill prevent any danger from the bulb igniting anything [illegible]sive if the shells should be crushed or punctured, as the [illegible] short [illegible]ircuit the lamp and the light is extinguished before [illegible]ulb is [illegible]roken.

*Conclusions.*—The tests made at the laboratories of the Drexel Institute and at the Frankford Arsenal (Appendices II. and III.) prove that these lamps are properly designed and substantially constructed, and that they are suitable for the use intended; also that the arcing which it is possible to obtain from the battery under conditions of service will not ignite explosive gases or materials.

Tests show that the heat from a man's body would not be sufficient to liquefy the solidified electrolyte and allow the solution to drip out of the battery to the ruin of clothing, or of possible personal injury.

These lamps provide a source of light which may be used in the presence of explosive vapours, gases, or other materials with a high degree of safety, even under extreme conditions of rough usage.

The breaking of the safety-glass, or the denting of the outer case of the reflector, will, in every case, extinguish the incandescent bulb. It should be understood that the breaking of an incandescent bulb, even of small candle-power, may, under favourable conditions, cause an explosion of a surrounding gas that has a low temperature of ignition.

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APPENDIX I.—INSTRUCTIONS FOR CHARGING AND CARE OF HIRSCH ELECTRIC MINE-LAMP BATTERIES.

*General Instructions when Received.*—When a new lot of batteries is received, put about a teaspoonful of distilled water in each, and put on charge as per No. 1 charging rate.

The small round terminal on top of the battery is the negative terminal; the flat copper clip on the side of the battery is the positive terminal.'

*Charging Current.*—Use only direct current (in no circumstances alternating current), and make sure that the resistance is sufficient, using either lamps or rheostats in series with the batteries.

*Charging Rate.*—Remove the hard rubber vent-plugs before placing on charge. Before charging, if the solidified electrolyte is too dry, add half-a-teaspoonful of distilled water in each. Start the charge at 1½ amperes for 2 hours, then reduce it to 1 ampere for 4 hours. If the batteries then read 3 or 3·1 volts, reduce the charge to ½ ampere, and continue to charge for about 2 hours until the batteries again read 3 or 3·1 volts.

*After Charging.*—The solidified electrolyte should always cover the plates to a depth of about ¼ inch, and must be moist and jelly-like.

After charging, allow the batteries to rest for three-quarters of an hour to solidify, after which pour off all excessive liquid. Then insert the vent-plugs.

*Cleaning.*—After each charge, wash the outside of the batteries in a solution of a tablespoonful of washing-soda and 2 gallons of water. Do not remove the vent-plugs. Wipe the batteries dry before placing them in the aluminium cases. Grease both the positive and the negative terminals of the batteries with vaseline immediately after washing; the terminals in the cases should also be kept clean and greased.

Place the batteries in the aluminium cases before handing the lamp to the user; also see that the contacts are firm and clean.

Add a teaspoonful of No. 1,200 electrolyte in each cell every two weeks.

*Renewing the Electrolyte and Solidified Solution.*—If at any time it is necessary to renew the electrolyte, remove the sealing compound with a heated screw-driver, then pull up by both terminal leads at one time both plates with the cover. Wash the plates under a stream of distilled water; replace the plates in a jar, covering them with No. 1,200 acid; reseal with sealing compound, and place on charge at the same charging rate as No. 1 at 1½ amperes at first until 2·9 volts are recorded across the terminals; then remove from the charging-rack, and drain off all 1,200-specific-gravity acid.

FIG. 3.—STORAGE-BATTERIES ON CHARGE FOR HIRSCH ELECTRIC LAMPS.

Immediately take No. 1,300 electrolyte, into which first dissolve an average teaspoonful of ammonium sulphate to a gallon of electrolyte; shake thoroughly, then mix six parts of this electrolyte with one part of solidified solution of a specific gravity of No. 1,180. Stir quickly and thoroughly, then immediately pour 2 ounces of the electrolyte into each battery, covering the plates about ½ inch. Let the battery rest for 1 hour, and then again place it on charge as per No. 1 charging rate.

*Caution.*—Never bring an open flame into close proximity with the batteries during the time when the batteries are charging or the solidified material is settling.

Batteries not in use should be recharged every 60 days, so as to keep them in good condition.

FIG. 4.—LAMP-RACK.

FIG. 5.—STORAGE-BATTERY CHARGING-RACK.

All connexions on the battery and in the battery-cases should be kept bright, clean, and greased.

*Short-circuits.*—A short-circuit is indicated by the battery registering in charge circuit between the terminals 2 volts or less for a continued period. Carefully remove the sealing compound, and slowly remove the plates from the jar. A careful examination will reveal the trouble, which may lie in the freezing of the active material between the positive and negative grids in consequence of broken leads, or in the carbonization of the wooden separators (should they exist). This trouble is due to abuse or lack of care in charging, either an overcharge in amperage, or an excessive long-continued charge at too low an amperage, or failure to examine the batteries at stated periods for the proper amount of moisture, the battery being too dry.

A special charging-rack (Fig. 3) is made, consisting of a series of formed flat brass springs mounted on a board. When a battery is inserted in the proper way, the springs make contact with the battery terminals, and when the battery is withdrawn the springs automatically form a closed circuit.

Figs. 4 and 5 are views of the racks used for the lamps and storage-batteries respectively.

APPENDIX II.—EXPLOSION TEST OF A HIRSCH ELECTRIC CAP-LAMP.

Drexel Institute, Philadelphia,
*February 24th*, 1914.

TEST No. 1.

| Alcohol, | Ether, | Air, |
|---|---|---|
| 1 volume. | 2 volumes. | 20 volumes. |

We tried to explode this mixture with a bunsen flame. No result.

TEST No. 2.

| Alcohol, | Ether, | Oxygen, |
|---|---|---|
| 1 volume. | 2 volumes. | 20 volumes. |

We tried to explode this mixture with a bunsen burner. Result—a violent explosion.

TEST No. 3.

| Alcohol, | Ether, | Oxygen, |
|---|---|---|
| 1 volume. | 2 volumes. | 20 volumes. |

We tried to explode this mixture with the spark produced by the Hirsch cap-lamp in series with the Hirsch storage-battery. Result—no explosion.

TEST No. 4.

| Alcohol, | Ether, | Oxygen, |
|---|---|---|
| 1 volume. | 2 volumes. | 20 volumes. |

Same as Test No. 3, except that a spark was produced in this case by opening a dead short circuit on the Hirsch storage-battery alone. Result—no explosion.

The mixtures of Tests Nos. 3 and 4 were carried to a bunsen flame after a spark test, and a violent explosion took place. The volumes in each case were not very accurately measured—the total volumes being 250 cubic centimetres.

J. L. BEAVER, *Instructor in Electrical Engineering.*
LEON D. STRATTON, *Instructor in Chemistry.*

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APPENDIX III.—REPORT ON HIRSCH ELECTRIC MINE-LAMP.

Frankford Arsenal, Philadelphia,
*February 28th*, 1914.

It gives me pleasure to make the following report on the Hirsch electric mine-lamp.

The current of the battery gives 2 volts and about half an ampere. The object of the test was to ascertain if, on breaking the circuit, the spark had sufficient intensity or heat to ignite the service explosives or the inflammable vapours or gasses that might be present in the magazines or storehouses.

The circuit was repeatedly broken while the ends of the conducting wires were embedded in—

(1) Nitrocellulose service small arms '30 Cal. powder (rifle).

(2) Small arms '38 Cal. (revolver) powder. A very fine-grained powder containing 60 per cent. of nitrocellulose and 40 per cent. of nitroglycerine.

(3) Short-fibre (fine) nitrocellulose (plain guncotton) containing 12 per cent. of nitrogen (approximately).

In no case were any of these ignited or inflamed, though the circuit was repeatedly made and broken, as was demonstrated by the extinguishment and re-ignition of the lamp, which was included in the circuit.

To test whether the spark would ignite the volatile vapours of alcohol and ether, sometimes found in magazines or powder stores, a copper vessel with glass front was evacuated by an air pump, and filled with the vapour of ether, volatilized from liquid ether contained in the copper vessel. Again the circuit was broken (as shown by the extinguishment and re-illumination of the lamp), but the ether vapour was not ignited by the spark.

These experiments demonstrate that the Hirsch electric lamp will be safe in any powder-magazine, casemate, or storage-house, if the circuit should be broken by some unforeseen accident and the circuit should fail to be short-circuited by the means provided in the lamp for this purpose.

W. J. WILLIAMS, F.I.C.

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## APPENDIX IV.—EXTRACT FROM TECHNICAL PAPER No 75.*

### TESTS OF THE HIRSCH LAMP.

The Hirsch lamp is designed for cap service, and was the second approved by the Bureau as permissible for use in gaseous mines. The safety devices with which this lamp is equipped are mounted in the headpiece and consist of an open-circuiting device that protects the lamp against blows from the front, and a short-circuiting device that protects the lamp against blows from the side. The open-circuiting device is operated by the breaking of a slip of window-glass, that is mounted directly across the inner surface of the bull's-eye glass, with which the lamp is provided. The breaking of this slip of glass releases a spring that interrupts the electric circuit of the lamp. The short-circuiting of the lamp is accomplished as follows:—The headpiece is made up of three concentric shells, separated by narrow spaces. The outer and inner shells are connected to the positive pole of the battery, and the intermediate shell is attached to the negative pole. These shells, of course, completely surround the lamp bulb, and the theory of the safety device is that the bulb can not be broken without so jamming these shells together that they will short-circuit the battery and thus extinguish the filament before it can ignite gas.

Forty-five tests were made upon this headpiece by striking it with the following tools:—A hammer, a wooden mallet, a tool shaped like a miner's pick, a piece of iron pipe, and a wooden club. Some of these tests were made while the headpiece was rigidly supported in various ways, and others were made while the headpiece was swinging from the end of its cord. The blows were struck with sufficient force to crush the headpieces, to shatter the glass in almost every trial, and to punch holes completely through the shells, but every time that the lamp bulb was broken the safety devices extinguished the filament. In some of the tests the lamp was protected by the circuit breaker and in others by the short-circuiting device.

These tests were not made in gas. The extinction of the filament was taken as the measure of safety, since the filament, if extinguished at all, is extinguished before the lamp bulb is broken, because the blow that breaks

* "Permissible Electric Lamps for Miners," by H. H. Clark, Technical Paper No. 75, *Bureau of Mines*, Pittsburgh, U.S.A.

the bulb must first destroy the slip of glass or jam the shells. As a matter of fact, the bulb was broken in only 7 of the 45 tests made, although one or the other of the safety devices acted in each test.

In order to find out whether or not the safety devices would extinguish the lamp unnecessarily, the headpiece and its cord were dropped 10 times upon a concrete floor from a point 6 feet above the floor. The safety devices acted in only one test, and the action was considered to be necessary, as the blow that tripped the circuit breaker also shattered the outer glass of the headpiece. These tests therefore seemed to prove that the safety devices are so designed that they will not cause the lamp to become extinguished unless it is desirable that it shall be extinguished.

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Mr. SIMON TATE proposed and Mr E. SEYMOUR WOOD seconded a hearty vote of thanks to Mr. Hirsch for his paper, which was cordially carried.

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Mr. JOHN GIBSON's paper on "The Logic of Trams" was taken as read, as follows:—

# THE LOGIC OF TRAMS.

By JOHN GIBSON.

*Introduction.*—A glance at the *Transactions* of the Institution and mining journals will show that while appliances for winding, pumping, hauling, ventilation, and other purposes have been exhaustively treated, the tram or tub has been much neglected. It is the "Cinderella" of mining appliances and "the maid of all work."

Collieries may exist without pumps, mechanical haulage, or winding-engines, but all possess one article in common—the tram. It is the appliance with which the workmen are brought most closely into contact. Perhaps on account of this it enjoys the most varied nomenclature, "wagon," "box," "tram," "tub," "hutch," "whirley," "corve," and "car" being some of the many names given to it. No scheme has been applied to the planning of it; and no co-ordinated thought has been devoted to its construction. In one colliery a 2-ton tram may be used, while under not dissimilar conditions a 4-cwt. tram may be employed in another. In one colliery a 14-inch gauge may be used, and in another a 42-inch gauge. Neither in the size of the tram nor in the width of the gauge can such differences be reconciled with reason. The differences are the result of haphazard design and want of thought.

The writer hopes to prove that the economical tram is of even greater importance than, say, the economical engine, and as no difficult and involved calculations are required, and all the governing facts are simple and well known, the former is more easily attainable than the latter.

Perhaps thousands of different types of trams and many widths of gauges are in use in this country. The waste and expense of such a want of system is appalling. Can it be said that the conditions are so diversified that all these types are necessary? Is it not easily practicable to reduce the number of these types to scores or even tens, and to standardize their

manufacture so that they can be turned out in thousands at a minimum cost?

In the first section of this paper the factors that determine the size and the construction of the tram are examined; whilst in the second section the road on which it runs is dealt with. The author earnestly begs that it be noted that these parts are not dependent the one on the other. The recommendations advocated in Section (2) may be partly or wholly adopted, although those in Section (1) are rejected, or *vice versa*.

(1) *What Governs the Size of the Tram?*—If a man were set to move coal a distance of 10 feet, the easiest and cheapest way would be to shovel it. If the distance were 10 yards, a wheel-barrow would be the most convenient article to employ, because it is easily tipped. If the distance were 100 yards, a side or end-tipping wagon holding 20 or 30 cwts. would perhaps be best. It follows then (other considerations apart) that the greater the distance is the larger the wagon should be. This rule is subject to important exceptions, however. If the gradient is more than 1 in 40, a man working single-handed would have great difficulty in pushing or controlling a wagon holding 20 or 30 cwts. It is therefore clear that inclination is an important factor, because in every colliery every tram is more or less man-handled. When the tram is underground, another important factor must be considered—the dimensions of the road.

The ordinary haulage-roads are usually big enough to take very large trams, but not so the gate-roads. In thin seams a predetermined minimum height and width of gate-road is set up by the size of the tram. If this be too large, either repairs of the road are excessive or new crossgates are frequent. In both cases the size of the tram governs the dimensions of the road, and is responsible for all unnecessary expense.

A man has no great difficulty in travelling in a road having a minimum height of 3 feet above the rails and a width of 3 feet between the narrowest timbers, and the writer suggests that the minimum or smallest sized tram should be $2\frac{1}{2}$ feet high and $2\frac{3}{4}$ feet wide.

Where the gate-road branches off the crossgate, the tram must often be turned at right-angles, and this is frequently and conveniently done on a turnplate. The width of the

road at this point determines the length of the tram, and one $2\frac{3}{4}$ feet wide by $4\frac{1}{2}$ feet in length overall can be turned on a road 6 feet wide and still allow of some little freedom of movement to the workman between the tram and the timbers. Such a tram, then, $4\frac{1}{2}$ feet long by $2\frac{3}{4}$ feet in width by $2\frac{1}{2}$ feet in height may be termed the No. 1 or minimum size. Wheels, etc., will be considered later, but if a weight of 3 cwts. be assumed in the meantime, it might now be considered what can be done with this tram.

In gate-roads it is (and more especially if the roof is tender) cheaper to draw by hand to the limit of inclination, rather than resort to self-acting inclines of any kind, because these require greater width; as a consequence, the handling of extra *débris*, heavier timber, etc., of course entails greater expense.

For short distances a well-developed young man can exert a force of 120 pounds. The writer has found that a force of 60 pounds can be usually given through a distance of 110 yards in $2\frac{1}{2}$ minutes without great exhaustion. This is equal to 0·24 horsepower. A lad of 14 to 17 can exert two-thirds of this force, that is, 0·16 horsepower. Assuming the co-efficient of friction to be a sixtieth, the man can push an empty tram weighing 3 cwts. up a road rising 1 in 6 for a distance of 110 yards in $2\frac{1}{2}$ minutes. A lad can tackle a gradient of 1 in $9\frac{1}{2}$.

It is worthy of notice that under unfavourable conditions, with the tare of the trams high compared with the gross load and a high co-efficient of friction, a self-acting incline would work on this road.

Consider now the relative importance of weight and friction. If the weight were increased from 3 to 4 cwts., the limit of inclination in the road mentioned would be 1 in $8\frac{1}{2}$ instead of 1 in 6. With a 3-cwt. tram, if the friction were doubled, the limit of inclination would be 1 in 6·9 instead of 1 in 6. It is clear, then, especially in roads rising towards the faces, that to keep the weight low is of far greater importance than to keep the co-efficient of friction low. Where the roads dip towards the faces, the case is slightly different. With a loaded tram weighing 10 cwts., the gradients are as follows:—

With one man behind the tram.

| Weight. | Friction. | Limit of Inclination. |
|---|---|---|
| 10 cwts. | $\frac{1}{30}$ | 1 in 49 approximately. |
| 10 ,, | $\frac{1}{60}$ | 1 ,, 27 ,, |

WITH TWO MEN BEHIND THE TRAM.

| Weight. | Friction. | Limit of Inclination. |
|---|---|---|
| 10 cwts. | $\frac{1}{30}$ | 1 in 13·5 approximately. |
| 10 ,, | $\frac{1}{60}$ | 1 ,, 11 ,, |

Roads dipping to the face are the exception rather than the rule. It is therefore clear that, especially in small trams, the weight must be kept down as low as sound construction permits, even if it involves a certain amount of increased friction. With larger trams the greater height of road permits of the use of ponies.

The writer is assuming that, where the trams are mechanically hauled on main roads, whether 100 or 150 horsepower is expended is of little consequence if the advantages gained close to the face where the trams are man-handled are sufficiently great. It is also clear that, as the weight and the carrying capacity of the tram increase, the importance of friction becomes greater.

It follows that wheels of small diameter and simple bearings are suitable for small trams, and that large wheels should be fitted to large trams. When a diameter of 14 or 16 inches is reached, friction may be most suitably reduced by ball or roller-bearings and high-class lubricating arrangements. In the case of the small tram referred to, perhaps an 8-inch wheel would be most suitable.

PROPOSED SCALE OF STANDARD TRAMS.

| Size. | Overall measurements. | | | | | | Inside measurements. | | | | | | Capacity. | Diameter of wheels. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Length. | | Breadth. | | Height. | | Length. | | Breadth. | | Height. | | | |
| | Ft. | Ins. | Ft. | Ins. | Ft. | Ins. | Ft. | Ins. | Ft. | Ins. | Ft. | Ins. | Cwts. | Inches. |
| 1 | 4 | 6 | 2 | 9 | 2 | 6 | 3 | 10 | 2 | 7 | 1 | 6 | 6 | 8 |
| 2 | 4 | 9 | 2 | 11 | 2 | 8 | 4 | 1 | 2 | 9 | 1 | 7½ | 7¾ | 9 |
| 3 | 5 | 0 | 3 | 1 | 2 | 10 | 4 | 4 | 2 | 11 | 1 | 9 | 8¾ | 10 |
| 4 | 5 | 3 | 3 | 3 | 3 | 0 | 4 | 7 | 3 | 1 | 1 | 9 | 9¾ | 11 |
| 5 | 5 | 6 | 3 | 5 | 3 | 2 | 4 | 9 | 3 | 3 | 1 | 10 | 11¼ | 12 |
| 6 | 5 | 9 | 3 | 7 | 3 | 4 | 4 | 11 | 3 | 5 | 1 | 11 | 12¾ | 13 |
| 7 | 6 | 0 | 3 | 9 | 3 | 6 | 5 | 2 | 3 | 7 | 2 | 0 | 14¾ | 14 |
| 8* | 6 | 6 | 4 | 0 | 3 | 8 | 5 | 6 | 3 | 10 | 2 | 2 | 18 | 14 |
| 9* | 7 | 0 | 4 | 3 | 3 | 10 | 6 | 0 | 4 | 1 | 2 | 4 | 23 | 14 |

* In sizes over 6 feet overall, the length, breadth, and height would increase by 6 inches, 3 inches, and 2 inches respectively.

NOTE.—The inside measurements and capacities are approximations only, and would vary according to the material used and the method of construction.

The above capacities are water measure.

The writer has no desire to lay down axioms as to what sizes of standard trams should be adopted, but he puts forward the preceding proposition as a basis for discussion. Starting with a tram 4½ feet long by 2¾ feet wide by 2½ feet high, in each succeeding size up to 6 feet overall the length, breadth, and height would be increased by 3 inches, 2 inches, and 2 inches respectively.

It would, of course, be easy, in the event of standards being adopted, to increase or decrease the depth of a tram so as to suit particular conditions. Thus one colliery finds that No. 9 is quite suitable except for the height, which is too great; or another colliery requires No. 3, but could take greater height. It is possible that standard trams would be somewhat unsuitable in some particular cases; but, even then, the advantages would be exceedingly great. A short examination of the present conditions will prove that statement.

When a colliery is about to be started, the owner may possess from one of his other collieries wheels, pedestals, under-frames, etc., and may determine to use the same or a similar type of tram in order to utilize the material and prevent repair and spare-part complications. The tram is almost certain not to be suitable for both the old and the new collieries. If the owner sets up a new type of tram, two classes of spare parts have to be stocked, and repairing generally becomes more expensive. Not only so, but, if No. 1 colliery urgently requires for a period extra trams, No. 2 colliery cannot render help, because the types are different. Or, again, a colliery is sunk to win a 7-foot seam and a 2-foot seam. The same tram cannot suit both. A compromise arrangement may suit neither, and the cost of changing is prohibitive. When a colliery is working, trams have to be bought at first cost; but when the colliery is exhausted, they are of little use to anyone, and are sold at scrap prices. It is not uncommon, therefore, to find that in collieries nearing exhaustion the trams are allowed to get into a state of low efficiency. With a standard tram the value at any period of its life would be well known. If, therefore, it were found that a particular tram was unsuitable for a certain colliery, another type would be obtained in exchange at a very small cost. Indeed, if the change were from a larger to a smaller type, the coal-owner might receive hard cash in addition to new trams. A different type might be used in every seam in the same colliery.

In a paper read before the Mining Institute of Scotland* the author stated that—

"A very common practice in Scotland is to pay the miner a hewing rate which includes drawing to a lye perhaps 500 yards out-bye. It will usually be found that two men are engaged in each place, one of whom hews the coal, throws it to the roadhead, stows the *débris*, and sets the timber. The other man fills the coal and draws it to the lye. Then if the tonnage rate is 3s., and 5 tons are produced daily, the wage rate is 7s. 6d. If 1s. per ton be taken as fair remuneration for the actual filling of the coal into the tubs, then the 3s. is apportioned as under:—

| | s. | d. |
|---|---|---|
| Hewing, etc. ... ... ... ... ... | 1 | 6 |
| Filling ... ... ... ... ... ... ... | 1 | 0 |
| Drawing ... ... ... ... ... ... | 0 | 6 |
| Total ... ... ... ... ... ... | 3 | 0 |

"If the road is 220 yards long, the rate per ton-mile is equal to 4s."

Three points may be noted:—(1) If the tram is large, a man of full physical strength is required, even on easy gradients, to provide for derailments; (2) while a lad has two-thirds the strength of a man, he is usually paid only half the wages; and (3) a drawer is but partly occupied, as waiting takes up more or less of his time. It follows, then, that if a third of a drawer's time is lost, the loss due to a man at 7s. 6d. per day is 2s. 6d., while that due to a lad at 3s. 9d. is 1s. 3d.

In the foregoing case, if trams suitable for a lad were adopted, the output for a man and a lad would be five-sixths of 5 tons, or, say, 83 cwts. The cost would be 11s. 3d., or approximately 2s. 9d. per ton—a saving of 3d. per ton, or 1s. 3d. for 5 tons, being the difference quoted above as due to difference in pay between a man and a lad.

Taking another case, in which the general gradient of the seam decreases from 1 in 8 to 1 in 12, with trams 10 per cent. larger the output would increase nearly 2½ per cent. for the same energy expended.

Again, it may be found that with a given size of tram road-repairs amount to 3d. per ton. It may be possible to reduce the drawing by 1d. per ton with larger trams by increasing the road-repair figure to 3½d., or, by adopting smaller trams, road-repairs may be reduced to 2d., and drawing costs increased by ½d. In

* "Mining Economics: Some Notes and a Suggestion," by John Gibson *Trans. Inst. M. E.*, 1914, vol. xlvii., page 258.

either case the saving of ½d. per ton is effected. In addition, if the roof becomes tender this may make the temporary adoption of smaller trams economical. If the roof becomes stronger this may have the opposite effect.

*Output and Length of Road.*—The tram having now been considered from the points of view of gradient, friction, size, etc., the question of output and length of road may be briefly considered.

*Example No. 1.*—In a colliery equipped with endless-rope haulage, where the distance from the shaft to the face is 2½ miles, let it be assumed that, the seams being thin, a 5-cwt. tram is used and the output is 1,000 tons. Each tub will make 2½ trips per shift, and will therefore carry 12½ cwts. of output. At least 1,600 trams must be used. With 2-ton trams at least 200 would be required. The difference in capital cost would be roughly £2,000 against the small trams; maintenance would also be higher with these; but with an output of 1,000 tons these would be small matters.

*Example No. 2.*—A road 1 mile long is equipped with main-and-tail-rope haulage for an output of 450 tons in 7½ hours. With a speed of 6 miles per hour only 15 trips per shift could be drawn, or 30 tons per trip. Allowing 5 feet for the length of each tram (with a capacity of 5 cwts.) and the coupling, with 120 trams in the set it would take lyes 200 yards long at each end of the road to marshal the sets—that is, nearly a quarter of the total length of the road. By doubling the speed and halving the time for changing, this would, of course, reduce the figures by half. It is clear that large outputs on long roads by small trams are impracticable with main-and-tail-rope haulage. If small trams must be used at the faces, and the road does not permit of the installation of endless-rope or such like haulage, it follows that the best policy would be to use small trams near the faces and very large trams out-bye.

The writer hopes that he has put forward not unfairly the case for standardization.

No mention has been made as to the material, whether iron, wood, or composite, of which the box and under-frame should be made. This is unnecessary, because once standardization has been adopted, trams could be made and stocked in all materials.

Of course, the further the purchaser travelled from ordinary material, the greater would be his risk of obtaining a favourable sale or exchange, unless his particular material or combination was successful.

With regard to construction, it must remain simple, especially for the smaller sizes. Springs such as are used for railway-wagons and protuberances such as grease-boxes and brakes are inadmissible, for these are unlikely to stand the rough usage.

(2) *The Track.*—Terminological difficulties in plenty crop up at every turn when the question of the rails on which the tram runs is considered, and particularly when the trams are man-handled. While Scottish idiom is usually rich and expressive, yet the terms used underground are often singularly inept. Thus, a "drawer" is a person chiefly employed, not in drawing, but in pushing. "Frog" and "heart" mean the same thing, unlikely as that may seem, and "wings" have not the slightest resemblance to anything used in flight. It is a great pity that terms for ordinary things differ so much in each coalfield throughout the country. The same word has frequently different meanings. Thus, in some districts, the person employed "drawing" is called a "putter," which name elsewhere denotes a person who assists the "drawer" at steep parts of the road. Again, "road" may mean the whole of the tunnel, gallery, or excavation leading from one point to another, as, for example, "gate-road," but may also mean the rails. Road, in short, is both a general and a particular term, and leads to such confusing information as "there are three sets of timber broken on the road," and the "trams are off the road." It therefore happens continually that the manager receives from his subordinates a requisition expressed in pit vernacular which he translates into the trade name before passing it through to the order clerk. Mistakes and delay must of necessity frequently arise. Probably with standardization adopted, and the name of each article stamped or cast thereon, this confusion of terms would abate or disappear, and terms common to the United Kingdom would be used throughout.

It is significant that for coal-cutter parts, electrical plant, and such like new appliances, the common trade names or scientific terms are used.

The American "track" is a distinctive term which the writer will use. A "short crossing" will be taken as the name of crossings of small radius, such as are used to lead from crossgates to gate-roads, and "long crossings" will be applied to those of long radius used on haulage-roads, auxiliary or main. The ideal track may be defined as composed of two parallel rigid conductors of suitable gauge, form, and material, lying in the same horizontal plane. If this could be attained in practice, derailments would be infrequent, and these are responsible for much of the cost of transit. Derailments on main haulage-roads need not be considered, because these tracks can be well constructed and maintained. Neither need the difficulties arising from soft floors be considered, these being particular difficulties and not common to all seams. Taking the case of derailment under ordinary circumstances for 200 yards out-bye from the face, it will be found that these are due to (1) faulty gauging and nailing, and (2) to defective sleepers. Even this inefficiency is expensive, because sleepers are used for timbering purposes, and nails are mislaid and buried in *débris*; indeed, not infrequently they reappear in the hoofs of the horses. The writer sees no way out of these difficulties, except by adopting some form of steel sleeper. Scarcity of timber and the great rise in price of wooden sleepers may bring this change about in the near future.

The length of the rails is a subject that receives little attention, and muddle often results as a consequence. For example: (1) the rails in a track are reputed to be 18 feet in length, and after a derailment one is seen to be defective and requires to be at once replaced. Then it is discovered that the new rail will not go in. Measurements show that while the defective rail is 17 feet 11 inches long, the new one is 18 feet 1 inch. (2) A replacement similar to the above cannot be done, because the rails are not uniform in type, and cannot take the same fishplate, or because perhaps the fishplate bolt-holes are not at equal distances from the ends of the rails in both rails. (3) A long crossing has to be laid, and a length, say, of 24 feet of the track has to be lifted to do so. The points are each, say, 2 feet 5 inches long, then 12 feet or more of rails are laid, after which the crossing 2 feet 11 inches long is laid. To "square" or bring even the crossing two pieces of rail each 2 feet 11 inches long must be used. It is then found that in order to join up the

original gap of 24 feet, two rails each 6 feet 8 inches long have to be used (Fig. 1, Plate III.). (4) A short crossing has to be laid into a narrow gate-road. The rails on the crossgate are too far in. If one length of rails be taken out, the rails are then too far out, and patchwork of short pieces of rail, or indeed wood, has to be resorted to. If the rails are too far in, the side of the gate-road has to be hewn, and the rails there form an awkward twist, as shown in Figs. 3 and 4 (Plate III.).

It is fairly evident that forethought and system can obviate all these drawbacks. By the adoption of a rail unit length and by making everything to suit that, economy and efficiency can be secured. Supposing that 4 feet is adopted as this unit, because it is an even number of feet, and because it is the longest rail that can be put into the minimum size of tram, and so taken safely and conveniently (which means cheaply) through the lowest road to the face: then light rails would be supplied in one-unit (4 feet) and one-and-a-half-unit lengths, in equal quantities of each; medium rails for auxiliary haulage in three-unit lengths (12 feet); heavy rails for main roads in three-, four-, or five-unit lengths, as was found most convenient; and gate-roads would be measured off by the rail-unit length, and not by feet or yards. Thus, if the practice were to set off gate-roads every 15 yards, that would be reduced to 11-unit lengths (44 feet) or increased to 11½-unit lengths (46 feet). All castings for crossings, turnplates, etc., would be made to suit. Thus, turnplates 4 feet square would be cast in halves, each 4 by 2 feet; short crossings 8 feet long would be cast or made in 4-foot lengths; and for long crossings, where rails are interposed between points and crossings, castings 4 feet long would be suitable (Fig. 2, Plate III.).

The simple principle underlying the proposed arrangement is that of having every rail and fitting of a known and predetermined length, and each long piece a multiple of the unit length. If the laying of the track is made simple and easy, rail-cutting and wood-patching is avoided. The actual work will be quicker, cheaper, and more efficient.

If the tram cannot be standardized in the near future, an effort should be made with the rail-gauge. Even in these times of national stress the passing of a one-clause Mines Amending

Act as under, setting up a standard gauge, should be no difficult matter, if once general agreement were attained:—

"In the case of every mine or seam newly opened after the commencement of his Act, no rail-gauge other than one approved by the Secretary of State shall be adopted or used for the transit of minerals."

If only one of the great coal-owners' associations, or even if a few of the large combines were to agree on the necessity and suitability of a standard gauge, the reform would gradually and automatically come about.

The possibilities for cheapness, convenience, and efficiency are tremendous. Standard wooden sleepers would result; improved universal steel sleepers would follow, and at least economize nails; standard crossings, turnplates, pointer-plates, fishplates, etc., would all come in turn.

If and when the next step, the introduction of standard trams, was reached, the possibilities would be almost boundless. Standard oilers, controllers, and tipplers would result. Standard hydraulic decking arrangements would be easy. Then, why not standard cages, leading on to headgears? The idea is not Utopian, but perfectly practical. If, before sinking was commenced, the coal-owner could say: "I shall use No. 3 up to No. 7 trams, and purpose using a three-decked cage holding six trams," it would be simply a matter of replying: "You require a shaft so many feet in diameter to take the standard cage, and the distance from pulley to pulley of the standard headgear for these cages is so many feet." There would be no fear of stereotyping and stagnation, because the cages, etc., though standardized in build and size, would permit of special fittings to suit newer ideas, and these, if satisfactory, would be incorporated on standard types.

The saving of clerical work would in itself be considerable, and liability to error in ordering would be much reduced. The manager would be saved from many petty worries, while the draughtsman would get useful work to do.

To revert to the standard gauge alone, each colliery must at present have all crossings, etc., specially made to suit the gauge. Here is an example of the waste involved. Some time ago a new form of crossing for a special purpose was suggested to the writer. He sketched it, and the work then passed through the hands of the draughtsman, the patternmaker, and the iron-

founder. Then the fitter adjusted it as far as possible, and the job was satisfactory, but capable of improvement in detail. If this appliance is of any value to anyone, it ought to be available, but except for those with the same gauge it is not, and in order to be adopted for another gauge the routine of the draughtsman, patternmaker, etc., is required all over again.

Controversy may not arise on the general but on the particular proposition, and as the writer is anxious that this should not occur, he approaches the question of discussing what the gauge should be with much diffidence. If it be assumed that 5 cwts. and 40 cwts. are the minimum and maximum capacities likely to be required, a basis for reasoning is available. He has mentioned 14 and 42 inches as about the minimum and maximum gauges at present in use, and the question which of these or what intermediate size should be adopted now arises. Taking the 14-inch gauge first, it is too narrow for use with horses and mechanical haulage, and it is quite unsuitable for a large tram. As for the 42-inch gauge, it is unsuitable for a small tram, and in narrow gate-roads with a fireclay or soft shale roof (or sides) the rails are normally obstructed by small *débris*. The standard gauge must be something between these. On light railways it is quite good practice to run wagons of more than 5 tons capacity over a 36-inch gauge, and on ordinary railways 32-ton wagons work on a gauge of 56½ inches. It is reasonable, then, to suggest that a 2-ton tram on a 24-inch gauge is a practical proposal, and that is the gauge which the writer respectfully suggests.

Reference might now be made to the length of wheel-base. It is well known that large trams require a longer wheel-base than small trams, and steep workings a longer wheel-base than flat workings. It is also well known that a tram with a long wheel-base requires a curve of rails of longer radius than does one with a short base, and this suggests a difficulty in standardizing crossings, etc., because, while a short-based tram would pass round any of the standard crossings, the long-based tram would not. This difficulty would be easily overcome either by making all curves such as would pass any tram, or by using standard crossings of, say, four classes to pass trams with wheel-bases of 2, 2½, 3, and 3½ feet. All except the longest based tram would go round at least two classes of curves.

Much is heard nowadays of national efficiency and of the organizing ability of the Germans. Here, in the subject of this paper, is just such a field as would suit them. If standardization would reduce the cost of production, the Briton, if he adopted it, would be armed for the better conduct of the economic war which will probably ensue, and would enjoy the added satisfaction of having beaten the enemy at his own game.

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Mr. WILLIAM M. KILPATRICK (Larkhall) wrote that Mr. Gibson's paper bristled with ideas and suggestions. Doubtless the author had made a strong effort to set forth the advantages that might accrue on the standardization of trams; but, in his (Mr. Kilpatrick's) opinion, the commendable feature of the paper lay in the author's insistence that considerable economy might be effected if the various more essential fittings used in the construction of trams could be more uniformly standardized so that under seemingly varied conditions these might be more easily reduplicated. He feared, however, that, like many otherwise capable advocates, in his endeavour to pursue this point, the author had travelled just a little too far and a little too fast. Mr. Gibson seemed to leave so little room for natural and individual predeliction, in a field, too, in which, according to the very nature of things, variety must ever predominate, that some of his more praiseworthy ideas and suggestions ran a danger of being overlooked in the irritation that might result from their apparent impracticability. For example: he (Mr. Kilpatrick) would never allow the size of the tram to govern the size of the side road, even if by accident that did seem to happen once in a while; and, if he were asked to give standard dimensions for a tram, he would never, no matter what its capacity was intended to be, construct it so that it would stand more than 40 inches above the rail. The principle that would guide him in this matter would be economy of the energy required to load the tram. From this point of view alone he would endeavour to keep the tram as low as, under the particular conditions, would be practicable, so that he might even make the minimum height less than 2 feet above the rail. Moreover, if he were set to win two seams, one 7 feet and the other 2 feet thick, through the same shaft, and presumably from the same bottom level, he would not introduce two different standard trams. The compli-

cation that this would involve, both at the pit-bottom and on the surface-tracks, to say nothing of cages, tipplers, etc., would, to him, be a sufficient deterrent.

The amount of work, too, which Mr. Gibson assumed he might legitimately anticipate as being available from a healthy man, namely, 0·24 horsepower, seemed somewhat high—especially when it was remembered that a Clydesdale horse was credited with being capable of performing only about two-thirds of the standard horsepower. He did not think that it would be wise to expect three men to be equal, even under the best of conditions, to a Clydesdale horse in the matter of "sheer haulage."

He (Mr. Kilpatrick) was not much in favour of "Government regulations" directing what track he should lay, or how he should lay it. There was one point, however, in connexion with the laying of these tracks that seemed too often to escape notice. He referred to the tilting-up of curves, especially on horse-haulage roads. It was sometimes painful to notice how persistently the outside of a curve was tilted up, no consideration having been given to the point whether the tram had got to be hauled round that particular curve or passed round by gravity. Hence it frequently happened that no effort was made to keep the resultant of what might be two almost opposing forces, under which the tram was being conducted, leading between the rails, with the troubles and losses consequent on many unnecessary derailments. To suggest to many mining officials that under certain conditions the inside of a curve should be tilted up was—strange though it might seem—to invite their ridicule.

Mr. W. H. Routledge (Abergavenny) wrote that several papers had been written on this matter and published in Monmouthshire and South Wales, one by Mr. J. Fox Tallis being of special value.*

He (Mr. Routledge) submitted that the views expressed by Mr. Gibson did not quite coincide with the modern practice of mining engineers in the United Kingdom. It had been for many years the universal custom at all large pits or groups of pits to instal a certain type of tram or tub and a certain width of gauge of tramway to suit the most economic requirements of the particular mine, and to extend as far as possible with minor improvements what had been decided upon

* "Colliery Trams," by J. Fox Tallis, *Proceedings of the South Wales Institute of Engineers*, 1900, vol. xxii., page 37.

as experience showed. The installation and maintenance of the type of tram and gauge of tram-road was duplicated as much as could be made convenient in the making-up of a tram or tub and the tramway upon which they travelled.

When it was considered that the use of trams or tubs and iron rails dated from the year 1767 at Coalbrookdale, and extended to other parts of the country shortly afterwards, he could not agree with the assertion that "perhaps thousands of different type of trams and widths of gauges are in use in this country." Many types of trams or tubs, it must be acknowledged, were in use, and followed the results of improvements, which had their particular intrinsic value, as in all other mechanical appliances. This was obviously the result of each engineer's own observation, which he converted into practice.

There were, however, two notable features in regard to the use and type of tram or tub—that since the advent of the coal-face mechanical conveyor, which enabled the management to dispense with many roadways, the introduction of a larger tram had been of advantage in the cost of working. A new condition also arose in designing a tram or tub to comply with the new Mines Act, which made it compulsory that the tram or tub should be reasonably dust-proof.

Mr. Gibson evidently had not suffered by recent legislation when he suggested that the Mines Act should be amended to set up a standard for underground tramways. The settlement of the gauge, if it were ever seriously entertained, would be probably more difficult than the celebrated "battle of the gauges," which raged for some years in the early history of railways, between the well-known civil engineers, Stephenson and Brunel.

The members of the Institute were ever ready to receive suggestions for the improvement of mining, and the practical remarks made by Mr. Gibson deserved their consideration.

Mr. JOHN WATSON (Kilmarnock) wrote that the importance of standardization of methods of manufacture of all kinds of material which were required in large quantities was too well known to require further emphasis; and it seemed strange that so late in the day it should be open for anyone to point out to mining engineers that there was still a field among such well-known objects as colliery trams for simplification of manufacture and for standardization of types and sizes. It might,

of course, be argued that it was more convenient for each colliery to make its own trams and to develop its own type, because the conditions under which the trams were to be used were known to the managers and to them alone, and that consequently the article best suited for the purpose in view would be produced. To extend this assumption, it would follow that each colliery should design and produce the rails and crossings best suited to its purpose, but that would be readily admitted without discussion to be impracticable.

On careful examination colliery-owners would no doubt find that it was quite practicable and decidedly advantageous that they should purchase rather than make their trams. It appeared to be possible to fix on a moderate number of standard types to cover the requirements associated with the coal-seams in the different districts. When this had been done, a specialist in the manufacture of trams would be able to produce both better and cheaper trams than could be made readily at a colliery. Of course, the work of repair would still have to be carried out at the colliery; but even that might be simplified, as the specialist would be able to supply every piece, either of metal or of timber, of the correct size and ready for application to the damaged tram. There had undoubtedly been great economies effected by the standardization of other material, and there was no reason, so far as he could see, to apprehend that similar economies would not be effected in the standardization of trams.

On the question of nomenclature, it appeared advisable to have standard names as well as standard articles. There was no doubt that much confusion arose, especially in buying, from the great variety of names used to describe the same thing. A workman or his foreman requisitioned material from the office by a word well known and understood, and could not appreciate that the use of this word which he understood so well should present any difficulties to a supplier in a distant part of the country, where a totally different word was cherished as being properly descriptive of the thing in question. Confusion often resulted, and it was much to be desired that, if standard sizes and types should be arrived at, then standard names for the parts and the objects themselves should also be associated with them. Much could be done in this way by stamping on each part its proper name, so that when replace parts were required no confusion need arise.

In the course of the work on a catalogue at present in course of preparation, the writer had experienced considerable difficulty in avoiding the use of a variety of words known to him and descriptive of machinery in use in coal-mining, many of which would convey nothing to readers in distant parts. The difficulty of arriving at words that would be universally understood had been a very real one.

Mr. WILLIAM SMITH (Dalmellington) wrote that the subject dealt with by Mr. Gibson had not received attention commensurate with its importance. Often a certain size of tub was adopted at a new colliery, not because the nature of the roof, height, and inclination of the seam had been considered, but because a neighbouring pit or seam was nearly exhausted, and a supply of tubs would be available. Mr. Samuel Dean* had attributed the high production per man in America to the use of cars of large capacity. Other American mining engineers had put it down to increased use of coal-cutting machines. Possibly both played an equally important part. That the size of the tub used had a certain bearing on output and wages cost was undoubted, even in the faulty and troubled areas worked in Scotland. For instance, in many cases a miner determined his day's work by the number of tubs filled. Assuming that he filled daily six tubs weighing 12 cwts. each, and earned 10s. per day, he required a rate of 2s. 9½d. per ton. If a tub holding 10 cwts. were used, or if the roof were allowed to come down so that a tub holding 12 cwts. only held 10 cwts, water-measure, then the tonnage-rate must be increased to 3s. 4d. per ton so as to enable the miner to make the same wage. Thus the tonnage-rate had to be increased 3½d. for each cwt. less that the tub carried. In a case known to the writer a tub holding 8 cwts. was gradually replaced by one carrying 10 cwts.; the men continued to fill the same number, the output rose 25 per cent. and wage disputes were considerably reduced. Managers who had been able to adopt underground conveyors had the importance of the subject strongly impressed on them. Tubs which formerly seemed adequate were found, with a conveyor at work, altogether inadequate, proving that, where hand-drawing was reduced to a minimum, one of the principal factors against increasing the size of the tub was removed.

* "Modern American Coal-mining Methods, with Some Comparisons," by Mr. Samuel Dean, *Trans. Inst. M. E.*, 1915, vol. l., pages 179 and 388.

With reference to the "track," it was certainly an advantage to have the rails in exchangeable lengths, say 18, 9, and 4½ feet; but he considered that the manager had already more than sufficient statutory responsibility to desire to run the risk of a prosecution for using a track over or under the statutory gauge, as might happen under the "Amending Act" suggested by Mr. Gibson.

Mr. SIMON TATE proposed and Mr. JOHN H. MERIVALE seconded a vote of thanks to Mr. Gibson for his interesting paper, which was cordially adopted.

Mr. JOHN GIBSON (Kilmarnock) wrote that he was grateful to the members for the kindly reception given to his paper.

No serious reasoned objection had been made to the proposition that the gauge of the track should be standardized. Exception had been taken by Messrs. Routledge, Kilpatrick, and Smith to the institution of a standard gauge by means of an Act of Parliament. In the first place, there was an alternative method advanced in the paper, namely, by voluntary agreement and arrangement. Even if legal enforcement was necessary, it would follow and not precede agreement. Secondly, the standard gauge of 56½ inches was legally enforced, and no one could suggest that this had been found irksome. The strictures passed on the recent mining legislation under which collieries were working should be made, not on its general wisdom, but on its application in all circumstances.

The regulations with regard to safety-lamps applied equally to the deep fiery mines of Glamorgan and to the shallow mines of Ayrshire, where firedamp was very infrequently found. This was undoubtedly an evil; but he awaited with interest an explanation of the reasons why the same gauge would be unsuitable for both counties.

Mr. Routledge had stated that he could not agree with the assertion concerning the existence of thousands of different types of trams. He (Mr. Gibson) wished, by two different ways, to show him that there was no exaggeration.

(1) It was admitted that at present everyone was at liberty (of which full advantage was taken) to design his own tram and gauge. Every tram had at least three dimensions, and it might be made of metal or wood, or both combined. The underframe, drawbar, pedestals, axles, wheels, rails, gauges, etc., might be

(and were) made in many varieties. There were thousands of pits in Great Britain, and until his endeavour to co-ordinate the known facts and lay down simple general principles, there was little or no guidance for owners and managers in choosing amongst this great variety of method and material. He had stated, therefore, that there were thousands of types of trams. This was a perfectly accurate statement, and to deny it was to go against all human experience: because, as there were many combinations of material and many heads to consider them, the types increased by geometrical progression. This could not be otherwise.

(2) To take a concrete case: a colliery group consisting of eight winding shafts had five different trams, yet there were only three different gauges, two different pedestals, four underframes, etc. Mr. Routledge might hold that there was only one type, because the method of construction was somewhat similar, or he might say in view of the pedestals that there were only two types, or perhaps three if judged by the gauge. He (Mr. Gibson) submitted that interchangeability was the only true test, and that the types were five.

He hoped on a future occasion to reply to the other points raised, as, for instance, that raised by Mr. Kilpatrick concerning the amount of work which a man was capable of doing. Mr. Kilpatrick had stated that he (Mr. Gibson) had taken too high a figure when putting 0·24 horsepower as the work which a fairly well-developed man could perform through a period of 2½ minutes. The figures were, however, founded on many years' observation. Text-books asserted that a man was capable of 4,300 foot-pounds per minute, if suitably applied for a period of 480 minutes. His own finding was that a drawer could under suitable conditions give 7,920 foot-pounds per minute for 2½ minutes. Was that at all incredible? It seemed as if Mr. Kilpatrick had forgotten the time factor.

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A "Widdas" patent incline chock was exhibited, described, and demonstrated by Mr. Percy Widdas.

A safety mine-cage arrester was exhibited, described, and demonstrated by Mr. Thomas Pearson.

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# THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,
HELD IN THE ROOMS OF THE SOCIETY, QUEEN'S CHAMBERS,
5, JOHN DALTON STREET, MANCHESTER,
FEBRUARY 8TH, 1916.

MR. LEONARD R. FLETCHER, PRESIDENT, IN THE CHAIR.

The following new members were elected, having been previously nominated:—

MEMBER—
Mr. ARCHIBALD EDWARD JONES, Neuadd, Porth (Rhondda).

ASSOCIATE MEMBERS—
Mr. HAROLD GREEN, Brackley Colliery, Little Hulton, Bolton.
Mr. MATHEW HENRY THORNE, Louzeiras da Companhia Inglerza, Rua Pedrão, Vallongo, Portugal.

## DISCUSSION OF DR. GEORGE HICKLING'S PAPERS ON "THE COAL-MEASURES OF THE CROXTETH PARK INLIER"* AND "THE GEOLOGICAL STRUCTURE OF THE SOUTH LANCASHIRE COALFIELD."†

Mr. W. OLLERENSHAW (Stockport) wrote that whilst agreeing that further researches in the northern, north-western, and south-western districts would prove the author's contention that the coalfield extended under the Permian rocks in some parts, he did not think that there was any probability of an extension of the coalfield towards the north-eastern and south-eastern portions, the upheaval of the Pennine Chain having, in his opinion, broken the continuation of the coalfield in that part of the county. He believed that the south-eastern part of the Lancashire coalfield would be found to lie in a basin-like trough, with its base a few miles north-north-east of Manchester. He thought that the con-

* *Trans. Inst. M. E.*, 1915, vol. l., page 322. † *Ibid.*, page 328.

flicting opinions held with regard to the configuration of the south-eastern part of the coalfield were due to the variation in the amount of dislocation or throw found in some of the principal faults intersecting that part of the field. One of those faults had a vertical displacement of over 400 yards at New Moss Colliery; but at Denton, about 3 miles to the east of the colliery, the displacement was only 30 yards. Another fault, which was supposed to have a displacement of 170 yards at Bredbury, had only one of a few feet at Denton, the latter being less than 2 miles away from Bredbury. The reduction in throw was in the case of the first-mentioned fault towards the east and in the case of the other towards the west. He would like to know what was the cause of that variation, and whether a similar phenomenon occurred elsewhere.

With respect to the Croxteth borings, the two holes, in his (the writer's) opinion, were placed in unsuitable positions, and a third hole, midway between them, should give much better data as to the value of that part of the coalfield. He agreed with Dr. Hickling that future researches would probably prove available seams of coal at a workable depth below the Permian, and he thought that the Society ought to lead the way in such investigations.

Dr. GEORGE HICKLING (Manchester University) said that Mr. Ollerenshaw had raised a number of interesting points. With regard to the possibility of a general extension of the Middle Coal-Measures under the Permian in various parts of the Lancashire coalfield, he noticed that Mr. Ollerenshaw agreed that there was a great possibility of workable Coal-Measures being found for some little distance, at any rate, within the Triassic boundary in the northern and north-western parts of the field, by which he presumed Mr. Ollerenshaw meant the southern margin from Pendleton westwards. That gentleman had expressed the view that in the eastern and north-eastern portions the workable Coal-Measures would not extend under the Permian, because of the breaks due to the Pennine uplift. He (Dr. Hickling) presumed that the idea was that along that particular edge of the field the Trias was faulted down against the Coal-Measures, so that by means of those faults the Middle Coal-Measures were carried to a considerable depth. In view of what he had seen since he read

the papers, he rather thought that this was the case. Along the western margin of that portion of the field, the middle part of the Coal-Measures would not be within reach, because the combined thickness of the Trias, Permian, and the Upper Coal-Measures was undoubtedly very great. At the same time, he believed that the old Bradford Coal-Measures (the Bradford Four-Foot and the Bradford Yard Seams) would be available, and would possibly prove workable under a considerable area. The main point that he had endeavoured to make in his paper was that the whole mass of the Coal-Measures swept round from the Poynton coalfield in a westerly direction, and that a considerable portion would be workable under the Triassic rocks to the north and north-west of Macclesfield.

With regard to the well-known Big Fault, which was cut through in a sinking at New Moss Colliery, Mr. Ollerenshaw had called attention to the fact that at Denton it had dwindled down until its displacement was only 30 yards, and no doubt it died away altogether a little further on. That, if one thought of it for a moment, was what all faults must do: they must vary from point to point and eventually disappear; there must be a point where there was a maximum throw, and from that point the throw must diminish until the fault died out. Many faults were what had been called "adjustment-faults." The strata, in addition to being faulted, were also very commonly thrown into anticlines and synclines. Just as a fault was a break which obviously could not extend indefinitely in both directions, so in the same way anticlines and synclines were wrinkles which did not extend indefinitely: in most cases they gradually died out in one direction and gradually increased in the other. In other cases the folds were broken across at right-angles to the crests and troughs: on one side of the break, the crest of the fold was high and the trough deep; on the other side, the elevation and the depression alike were less marked. As a result, the dividing fracture was a fault which had the downthrow on one side where it cut the crest of the folds, and on the opposite side where it cut the trough. Such were "adjustment-faults." There were numerous examples in the Lancashire coalfield of adjustment-faults leaving in one part of their course their upthrow on one side: this, when traced along, gradually died out; and, if traced still further, the upthrow was found on the opposite side.

Mr. JOHN GERRARD (Worsley) said that the knowledge with regard to changes in the faults in the Lancashire coalfield could be very much extended if the coal-owners would give to Dr. Hickling any information obtained in connexion with their workings. Within the last few years it had been discovered that the large Ashton Moss Fault diminished very much southwards, and it would be interesting if Dr. Hickling could trace that fault to the north of Ashton Moss, in order to ascertain what the conditions were in that area. He (Mr. Gerrard) found in some quarters a feeling that in offering such information those possessing the plans would be giving something away which seemed to them valuable; but he ventured to think that the return obtained from Dr. Hickling's investigations would be far more valuable than the information that they gave to him. Coal-owners in Lancashire had, at present, a splendid opportunity of securing the services of a trained geologist, and it would be most unfortunate if that opportunity were allowed to pass by without the fullest advantage being taken of it. No fear need be felt of any breach of confidence, and if the members could render any assistance in obtaining a correct survey of the Lancashire coalfield, he hoped that they would not hesitate to offer it.

Dr. HICKLING said that he should like to emphasize the appeal made by Mr. Gerrard for the fullest information on the points raised in the paper. Whatever data were forthcoming would be treated absolutely as confidential, and would not be published in any form without the permission of those who supplied it. As illustrating the importance of the work, he might mention that certain investigations in the direction of the correlation of the seams at one colliery had made it quite clear that a short distance below the seam which was being worked there was a very great probability of another seam being discovered, the presence of which had not hitherto been suspected. That, of course, was quite beside the far more important general question of proving the ultimate extension of the Lancashire coalfield. Although the matter was one which, perhaps, did not immediately concern the present individual colliery-owners, nevertheless, if the work were carried through, there was sure to accrue a large amount of information of great value to collieries actually being worked at the present moment.

Mr. J. Drummond Paton (Manchester) said that when the question of the national resources of the country were dealt with, attention should be given to the fact that there were millions of tons of inferior grades of coal which were not used at all. The existing method of firing and utilization of coal necessitated the presence of certain special qualities, and it would be interesting if Dr. Hickling could collect such information as would enable him to give some estimate of the value of bastard coals and cannels in the Lancashire area. It was an established truth that in the future the value of coal would not be determined simply as it had been in the past—namely, by its boiler-firing capacities. The present demand for oils, aniline, etc., had changed the aspect of valuation, and that which was not recovered and estimated as bastard and waste coals would certainly occupy a more prominent place in the future. In consequence, a record of such seams might be co-ordinated with the work carried out by the officers of the Geological Survey, and such an investigation would provide immediate increments of coal which a purely geological survey would not be likely to produce in the near future.

Dr. Hickling replied that in his paper he had given a slight hint in that direction. He agreed that at the present time not only was a great deal of coal being wasted by being left behind in the collieries, because owners did not consider it worth while to work it (in other words, it did not pay), but the coal actually taken out of the pits was being wasted to a very large extent by not being used in the most suitable manner. In his opinion, within the next ten years or so there would be an enormous development in the utilization of coal-products of all kinds, and it looked very much as though coal, merely as a fuel, might before long come to be almost of less value than coal as the raw material from which various valuable products would be obtained. At present practically nothing was known as to the relative values of different coals as raw materials for obtaining particular bye-products. A great deal of research was required in the way of ascertaining the most suitable ways of using special classes of coal. In the first place, it would be necessary to attempt a scientific classification of coals, which they were very far from possessing at present, and then to make a thorough study of the industrial possibilities of each class. That opened out an enor-

mous field for research, one which, in his opinion, was urgently required.

Mr. SYDNEY A. SMITH (Manchester) said that the Big Fault at New Moss Colliery mentioned by Mr. Ollerenshaw died away to nothing a little further east of Denton, as the Roger Mine levels were practically at the same depth on opposite sides of the fault. Still a little further east it became a "reverse" fault, with a downthrow of about 25 yards, as proved in the Black Mine at Hyde Lane Colliery. Although proved in that mine at a much greater depth and at a considerable distance to the east, owing to the inclination of the fault, it was undoubtedly the same fault. Some of the previous speakers seemed to think that the effect of that fault had but recently become known, though its position and effect were presumed about 20 years ago. A tunnel was driven at New Moss Colliery shaft, at a depth of some 450 yards, through broken ground, to prove whether that presumption was correct, and it was found to be approximately so when the Great and Roger Mines on the western side of New Moss Colliery were discovered. When the fact was taken into consideration that a fault with an upthrow of 30 yards was estimated to become an upthrow fault of over 400 yards at a distance of about 2 miles, and this assumption afterwards proved to be approximately correct, it was a somewhat remarkable instance of the application of geology to practical purposes.

Mr. HAROLD STEPHENSON (Tyldesley) pointed out that in the Wigan area the dip varied largely from south to east—so much so that in one instance what should have been a level turned out to be a down-brow. He agreed with Dr. Hickling that the dips in the faulty districts were invariably less regular in direction and extent than in the more favoured areas.

Dr. HICKLING said that everything in that area was intensely disturbed. They would get what might be described as a "smooth run" of Coal-Measures from Pendleton to the Haigh Fault; but, as soon as they crossed that fault, they got into an area where the strata were simply topsy-turvy. Dips were discovered directed to almost every point of the compass, but the general run of the outcrops was from north-north-west to south-south-east. From the Haigh Fault to Manchester the rocks were

comparatively unbroken, although several important faults occurred. The term "Wigan Smash" was used to emphasize the fact that the strip which included Wigan was greatly faulted; the whole structure of that area was altered in relation to those faults, and, instead of the strata striking east and west, they trended for the most part north and south.

Mr. H. O. Dixon (Westhoughton) asked whether it was possible to appoint a small committee to deal with the survey of the Lancashire coalfield, and suggested that separate areas should be dealt with locally. If colliery managers and others interested could meet together and mark on an Ordnance map all the known faults in their respective districts, and then send it on to Dr. Hickling, the information obtained would prove of great service in the work which he had in hand. In his (the speaker's) own district there were a number of faults unknown to other persons, and he was quite prepared to give whatever information he had concerning them.

Dr. Hickling said that the idea was excellent, and would be of immense assistance to him if the members could carry it out.

Mr. W. Pickup (Blackburn) said that there might be individual instances where there would be some objection to the imparting of information, but in the bulk of cases he was quite sure that there would be little difficulty and the owners would readily co-operate and assist in any efforts required to make the work Dr. Hickling had undertaken a success. Some years ago, when a certain section and plan were being prepared, and Mr. Gerrard had to approach the colliery-owners on the route, serious difficulty was experienced in obtaining the information that he required.

The President (Mr. Leonard R. Fletcher) said that a sub-committee had already been appointed to deal with the matter, and any suggestions made by the members would be carefully considered by it. In his opinion the question was of such importance that it ought not to be allowed to drop without the intimation of some definite action. He failed to see why there should be so much secrecy about information as to what was

found in the bowels of the earth. Secrets of the kind did not really belong to those who found the faults, because the influence of the faults extended far beyond the boundaries of particular collieries. He hoped that a great deal of information would be obtained and placed at the disposal of investigators such as Dr. Hickling, so that the greatest possible advantage might be derived from it for the good of the country generally. It seemed to him that there was enough work arising out of the knowledge constantly obtained by discoveries in connexion with colliery workings to keep a geologist busy at all times, and he hoped that no such secrets need be kept from the committee.

Mr. H. STANLEY ATHERTON (Bolton) suggested that, in order to help Dr. Hickling, it would be wise to use a 6-inch Ordnance map, to show on this the fault on the surface, then its position as proved in the mines, and the variation of dip or divergence from the general line (if any), but if there were none, the position as proved in the highest and lowest mines, with the depth where proved.

Mr. GERRARD said that in some of the newer portions of the coalfield, where arrangements had not been made with the lessors, it would be a little difficult for owners to publish freely any information which might be used by the lessor to the disadvantage of a particular lessee. He could quite understand why a lessee, until he had made arrangements in regard to royalties and so forth, should wish to keep such information to himself. That, however, did not apply to the whole coalfield, and he hoped that the coal-owners would do what they could to help Dr. Hickling.

The further discussion of the paper was adjourned.

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The HON. SECRETARY read extracts from the following paper by Prof. X. Stainier on "The Connexions Between the North-Western European Coalfields":—

# THE CONNEXION BETWEEN THE NORTH-WESTERN EUROPEAN COALFIELDS.

By Prof. X. STAINIER, D.Sc.

*Introduction.*—The discovery of the Kent coalfield has filled one of the many blanks in the geological map of the Palæozoic deposits of North-Western Europe. Our knowledge of the Kent coalfield has been derived almost entirely from papers published by Prof. W. Boyd Dawkins, Dr. Malcolm Burr, Dr. Newell Arber, and Mr. H. Bolton. Still much remains unknown of the geology of South-Eastern England, and, until we know more, divergence of opinion regarding it will continue.

The connexion between the Kent and the Continental coalfields on the one hand, and the western British coalfields on the other, has been for many years a controversial subject between geologists. These coalfields were once considered as detached portions of a former extensive sheet of Carboniferous deposits, but some geologists seem now to incline to the view that they were never connected. The writer ventures to enter into this interesting discussion, and hopes to show—

(*a*) That the problem is one of the most difficult of geological investigations;

(*b*) That we are still far from a perfect solution thereof; and

(*c*) That both of the extreme theories must be set aside.

This problem long ago received the attention of geologists, especially in England, where there are so many detached coalfields. But it was only after the excellent paper of Godwin-Austen (1855) that the question received a vigorous impetus. Ever since then the most illustrious geologists in England and on the Continent have been at work on the subject; and one may find a good summary of the opinions of Murchison, Ramsay, Prestwich, Hull, and others on the question, in the Reports of the First Coal Commission (1871), and of more modern views enunciated by Strahan, Lapworth, Kendall, Boyd Dawkins, and others in the Reports of the Second Coal Commission (1905).

During the last 25 years much work has been done, from which valuable information may be gathered, and the writer may mention (1) Vaughan, Sibly, Dixon, Garwood, and others who have devoted themselves to a much neglected task, namely, the minute study of the lithological division and the zonal sequence of the Carboniferous Limestone; and (2) W. Hind, Gibson, Ward, Stobbs, Vernon, and many others who on the one hand, and Kidston and Arber on the other, have performed the same work, respectively, on the faunal and floral sequence in the Coal-Measures. In addition, the re-survey of most of the important coalfields has provided us with accurate stratigraphical knowledge and maps relating to them. (3) In the North of France, in Belgium, and in the Rhenish Provinces much work has likewise been performed in the same way, and even new coalfields have been discovered. (4) In Holland, the latest coal-producing country, the State prospecting survey, under the able guidance of Dr. W. Van Waterschoot Van der Gracht, has filled many blanks between the Continental and insular coalfields. Thanks to this work of minute zoning, instead of the large and often ill-used names and divisions, such as Carboniferous Limestone, Coal-Measures, Millstone Grit, etc., we have minute subdivisions, and the knowledge of their fauna and lithology. Moreover, the great geographical extent of those subdivisions furnishes a precious supply of information relating to the physiography of North-Western Europe in Carboniferous times. We are aware, therefore, that the earth's crust, in Carboniferous times, was not less active than in any other period. Continual geographical changes took place in consequence, and it is no more possible to condense, on one map, the geographical history of the Carboniferous Period than to summarize, on one map, the vicissitudes of the Roman Empire. The extensive sheets of Carboniferous deposits represented by some palæogeographical maps are the result of a mixture of widely different subdivisions of the geographical history of the Carboniferous Period.

How much some of the sheets ought to be reduced is a question to be settled only after a careful study of the connexions, past and present, of the detached basins. Any attempt to trace the outlines of the detached, and sometimes concealed coalfields, depends essentially on the advancement of our knowledge of (1) the physiography of North-Western Europe in Car-

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boniferous times, from which we may infer the original extent of the coalfields; and (2) the result of the denudations to which these coalfields have been subjected so as to bring them to their present state. The writer proposes to study the problem under these two headings.

## Part I.—Physiography of North-Western Europe during the Carboniferous Period.

Doubtless the most important factors of physiographical conditions are the mountain ranges, for not only do they influence the distribution of land and water, but they are also paramount in all the questions of climate, water-courses, erosion, sedimentation, and life-zones. The post-Carboniferous mountain ranges are especially connected with the problem of denudation and the disseverance of the various coalfields. The pre- and inter-Carboniferous earth-movements are connected with the other questions quoted above. Such is the importance of the knowledge of mountain-formation for the present purpose that the writer feels compelled to cover some ground which is familiar to geologists. Two mountain ranges only are of interest in connexion with the problem of the coalfields: (*a*) the Caledonian range (Ed. Suess); and (*b*) the Hercynian range (Marcel Bertrand). Before and after the Carboniferous Period they covered North-Western Europe with such a net of ridges and troughs that some classification is needed, with suitable terminology, in order to avoid misunderstanding. The classification of the principal ranges, with their most important characters, is therefore embodied in the following table:—

| Mountain range. | Fold. | Trend. | Direction of impulse. | Names. |
|---|---|---|---|---|
| Caledonian* | Longitudinal† | N.E. to S.W. | N.W. | Caledonian.† |
| | | N.N.E. to S.S.W. | S.E. | |
| | Transversal | N.W. to S.E. | | Charnian.† |
| Hercynian* | Longitudinal† | E. to W. | S. | Hercynian. |
| | | E.N.E. to W.S.W. | | |
| | | W.N.W. to E.S.E. | | |
| | Transversal | N. to S. | E. | Malvernian.‡ |

* See Appendix I., page 145. In order not to encumber the statements with the details of necessary evidence, the writer embodies them in appendices to this paper.

† The names used were adopted by Prof. Charles Lapworth (Appendix III., No. 64, page 225), but are slightly modified in this paper so as to adapt them to the whole of North-Western Europe.

‡ See the sketch-map (Fig. 3, page 147) showing the principal Palæozoic anticlines of the British Isles.

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(1) *Caledonian Folds.*

(1) *Main Anticline*: Stretching from the Highlands of Scotland to the Highlands of Ireland (Donegal).

(2) *Main Syncline*: Stretching from Edinburghshire to Tyrone and Mayo.

(3) *Dumfriesshire Anticline*: Stretching along the Southern Uplands of Scotland to the North-East Highlands of Ireland and County Galway.

(4) *Solway Syncline*: Stretching from Northumberland to County Clare.

(5) *Westmorland-Wicklow Anticline*: Stretching from the Lake District to County Wexford.

(6) *Wexford Syncline*: Hardly distinguishable, being for the most part under the water of the Irish Sea and veiled by subsequent deposits.

(7) *Welsh Anticline*: The Uplands of Wales.

(8) *Anglo-Belgian Syncline*: From the Borderland of Wales a large area of unknown ground stretches to the uplands of Belgium. Doubtless many synclines or anticlines cross this area, but they are overlain by such a thickness of sediment that any attempt to trace their course to-day would be fruitless. In the Lower Silurian inlier of Veryan (Cornwall) we have, perhaps, a small part of one of these folds which escaped the Hercynian disturbances, with a piece of the north-east to south-west shore of the Lower Devonian sea.

(9) *Condroz Anticline*: A Silurian belt stretching along the Sambre and the Meuse, some part of it being doubtless of Caledonian origin.

(10) *Dinant Syncline*: Stretching over Northern France and Southern Belgium. Minor pre-Devonian anticlines protrude in this extensive syncline; but its southern limit is buried under the strata of the Paris Basin, and is unknown.

(2) *Charnian Folds.*

(1) *North Wales-Woolhope Axis*: This is the most conspicuous Charnian fold, running along the shorter axis at times in the form of anticlines and synclines, from Holyhead* to Carnarvon, Dinas Mawddwy, Newtown, and Knighton; near Penbridge, it disappears under the Old Red Sandstone and reappears

* And perhaps from Donegal through the Mourne Mountains (see Fig. 3, page 147).

along the Woolhope anticline; then it crosses May Hill, and disappears under the Trias.

(2) *Charnian Range*: Protruding above the plains of Leicestershire, Warwickshire, and Worcestershire, and seen as the inliers of Charnwood Forest, Hartshill, Dosthill, and the Lickey Hills. After a long and still mysterious history, it became refolded in a series of parallel (nearly north-west to south-east) ridges as a structure of the Caledonian range, and this was not the last event of its history.

(3) *Hercynian Folds.*

(1) *Main Anticline*: Stretching from Brittany to the Vosges.

(2) *Littry-Saarbrück Syncline*: Stretching from the coalfield of Littry (Calvados) to the coalfield of Saarbrück.

(3) *Cornwall-Hartz Anticline*: Stretching from Cornwall (Lizard) and Cotentin to the Ardennes, the Hunsrück, the Taunaus, and the Hartz.

(4) *Devon-Dinant Syncline*: Stretching from the extreme South of Ireland to Devon, and across the North of France to the Dinant Basin and to the Culm Basins of Nassau.

(5) *Mendip-Condroz Anticline*: Stretching from the mountains of Kerry (Ireland) to South Pembrokeshire, the Mendips, the axis of Artois, the Condroz anticline, and thence to South Westphalia.

(6) *South Wales-Namur Syncline*: Stretching along the coalfields of County Clare, South Wales, Bristol, Kent, the North of France, Namur, Wurm, and South Westphalia.

(7) *Wales-Brabant Anticline*: Stretching from the mountains of South-East Ireland to Wales and the *massif* of Brabant.

(8) *Midlands-Campine Syncline*: Stretching from the centre of Ireland, where it is in contact with the No. 6 syncline, to the Midland coalfields, and thence to South Holland and the Campine, where it comes into contact again with Syncline No. 6 and runs with it to Westphalia.

(9) *Westmorland Anticline*: Stretching from Louth to the Isle of Man, the Lake District, and North Yorkshire.

(10) *Cumberland-Northumberland Syncline*: Stretching from Monaghan to the Cumberland and Newcastle coalfields.

Nos. 11, 12, and 13 folds are identical with the Nos. 1, 2, and 3 Caledonian folds.

### (4) *Malvernian Folds.*

(1) *Pennine Chain*; (2) *Malvernian Range*; (3) *Usk Anticline*: The writer will describe these hereafter.

(4) *Samson Anticline*: Severing, in Belgium, the coalfields of Hainaut and Liége, but this is of very limited extent.

(5) The much more important anticline of Old Red Sandstone severing the Wurm and Eschweiler coalfields from the Ruhr coalfield. Both Nos. 4 and 5 anticlines have a north-north-westerly trend.

### (1) PHYSIOGRAPHY OF THE LOWER CARBONIFEROUS PERIOD.

The Carboniferous Basin of North-Western Europe may be described as a broad east-and-west belt bounded northwards by the main ridge of the Caledonian range and southwards by the main ridge of the Hercynian range. The building-up of the Caledonian range had covered this belt with parallel ridges and troughs before the Devonian Period. A range is destined to disappear sooner or later by erosion and subsidence. During the Devonian Period the Caledonian range had already shown signs of weakening. The southern outskirts of the range, at least up to a line drawn through Bridgewater, London, Brussels, to Düsseldorf, were already under the waters of the sea. In the meantime freshwater lakes filled the troughs of the range in Scotland, Ireland, and Wales. Nevertheless, on the eve of the Carboniferous Period the British Isles were still a mountainous country. During the Lower Carboniferous Period the progress of disappearance took a rapid course. Concurrently with a general subsidence, large tracts of country (*Graben*) gave way along and across the ridges, until at last nothing but the very top of the ridges stood, at distant intervals, amidst sunken ground.

### (1) *Tournaisian Period.*

*British Isles.*—The sea overstepped its Devonian shores and invaded Somerset, Gloucestershire, and South Wales. The identity of fauna and rocks of the outlier of Oreton in the Clee Hills of Shropshire demonstrates that a bay of this sea extended, between the Malverns and the Welsh Borderland, as far as Shropshire. Through the studies of Vaughan (Appendix III., No. 70), Sibly (No. 55), and Dixon (No. 23), one may represent, by the

diagram shown in Fig. 1, the distribution of the rocks of littoral type (sandstone) and of pelagic type (limestone) in the Lower Carboniferous strata of this bay, before the foldings and denudations.

From this diagram one may infer: (1) that the shore of the sea was in Shropshire; (2) that during the invasion the sea reached at once its greatest extent; and (3) that soon afterwards a gradual upheaval took place, driving back (southwards) the sea during the whole Lower Carboniferous Period. Large tracts of Southern and Central Ireland were also invaded by the Tournaisian sea, and during this period the Irish Sea stretched, perhaps through the Solway syncline, round the Lake District, where Tournaisian deposits of normal type have been detected (Garwood, Appendix III., No. 25). It is perhaps also through Ireland that the sea invaded the main syncline of Scotland, bringing the marine episodes of the Calciferous Series and turning round the eastern end of the Dumfriesshire

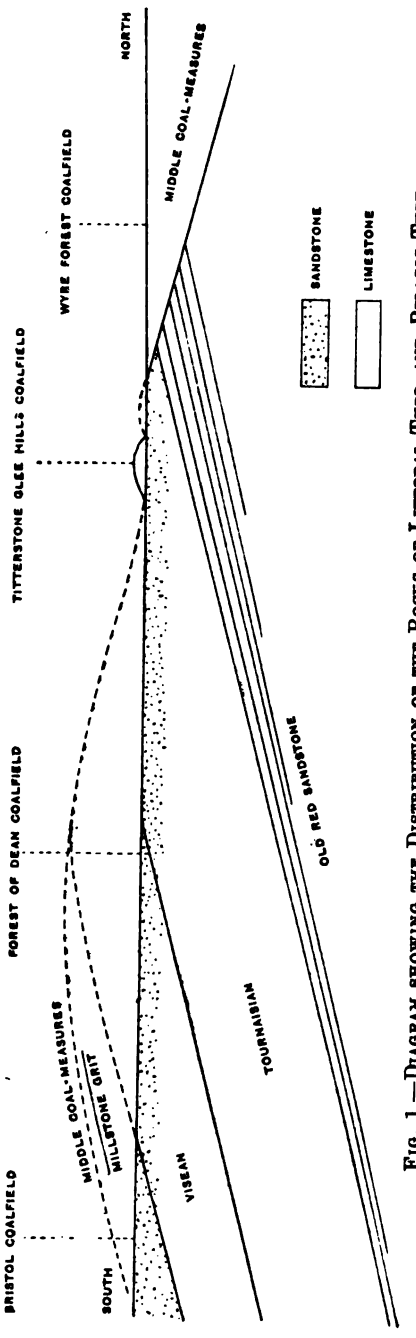


FIG. 1.—DIAGRAM SHOWING THE DISTRIBUTION OF THE ROCKS OF LITTORAL TYPE AND PELAGIC TYPE.

anticline, it played the same part in the Tuedian rocks of North-Eastern England. Stratigraphical and faunal evidence, to prove the existence of the Tournaisian in Cornwall and Devon, is still very weak. It is quite certain, however, that this Tournaisian should be very different from the other contemporaneous deposits, except, perhaps, from the coeval rocks of Southern Ireland. There is no actual evidence of any other Tournaisian deposit elsewhere in the British Isles.

*North of France and Belgium.*—An unbroken sea doubtless covered* these countries south of the Brabant anticline and up to the Ardennes, and nowhere do its sediments display shore-conditions. We may therefore presuppose a large extent of this sea northwards and southwards. Towards the north-east, near Liége, the Tournaisian thins out and disappears, overlapped by the Viséan, and is wanting in the Visé inlier, and in the Campine for the same reason.

*Rhenish Provinces.*—The same unsettled problem as in Devon presents itself in many Culm-deposits of the right bank of the Rhine. The remarkable similarity of the rocks and fauna of the Tournaisian of the Continent with those of the British Isles has been pointed out long ago, and is still much more striking, as shown by the results of careful zoning of both. There is no doubt that these deposits were laid in one and the same sea stretching from Ireland to the Rhine, and therefore the discovery of Tournaisian rocks in South-Eastern England is highly probable.

### (2) *Viséan Period.*

The general subsidence of North-Western Europe was still more important during this period.

*British Isles.*—The local upheaval of Shropshire, which has been already noted (Fig. 1),† seems to have produced along the northern margin of the Wales-Brabant anticline a land-barrier stretching from North Wales to Charnwood Forest, and perhaps further eastwards‡; but elsewhere, the whole of Great Britain,

* The Tournaisian is wanting in the Boulonnais between the Viséan and the Upper Devonian (Appendix III., No. 33, page 16).

† See page 105.

‡ The so-called "Mercian Highlands," a name which takes much for granted, but it is used here for the sake of convenience.

south of the Scottish Highlands, seems to have been submerged beneath the waters of the Viséan sea. The history of the disappearance of the land north of the above barrier is a long and interesting one. During the Devonian Period a gap or transversal valley had already appeared in the eastern end of the Dumfriesshire anticline, in Berwickshire. Through this gap the waters of the Old Red Sandstone lakes of the main Caledonian syncline crossed the anticline, and stretched all along its southern slopes from east to west. During the Tournaisian, the Scottish waters invaded the North of England by the same gap, and also by a new one, westwards, in Nithsdale; in addition, the sea stretched from Ireland as far as Westmorland. During the Viséan Period the sea of Northern England made for the south, rolling on its way the pre-Carboniferous rocks and depositing them on its red basement beds. The Midlands, the Isle of Man, and Anglesey were covered by its waters, and, taking advantage of the rugged ground of the Mercian Highlands, the sea, towards the end of the period, invaded some deep furrows of the Palæozoic floor, which formed the future site of the coalfields of Coalbrookdale, South Staffordshire, and Leicestershire. A line drawn from the Wrekin to Cannock Chase (Appendix III., No. 17) and to the Desford boring, Leicestershire (No. 24, pages 104 and 147) seems to be close to the southern shore of this sea. Viséan rocks have been struck by many borings in Kent. From the characters of the rocks and fauna it is evident that the Viséan sea of Kent was widely connected with the neighbouring Viséan seas. The Kentish Viséan rocks have not yet shown the sandstones and pebble-beds that are so common in the coeval rocks of South-Western England, and they give evidence of a former extensive sea in South-Eastern England. The curious inlier of peculiar Viséan rocks found in the borings of Gayton and Northampton also prove the extent either of one of the bays of the Midland sea or of the sea from the south, as suggested by Kendall (Appendix III., No. 2, Part IX., page 28). Other evidence that a great portion of the South of England was covered by sea is furnished by the enormous mass of Carboniferous limestone pebbles found in the conglomerates and breccias of the Upper Coal-Measures, Permian, and Bunter of the Midlands. From a study of the papers published on these rocks, the writer is convinced that most

of these pebbles came from the south.* Therefore the only areas besides the Mercian Highlands where the existence of the Viséan sea in England may be questioned are the Lake District and Wales, which were formerly spoken of as islands in the Lower Carboniferous sea. As to the Lake District, a fresh study of the question by Marr and Garwood (Appendix III., No. 25, page 552) has proved that Viséan deposits once extended over the district. As to Wales, A. Strahan (Appendix III., No. 63, page 536) has explained the grounds for believing that a part, at least, of North Wales was included in the Viséan sea. In South Wales the character of the Viséan deposits of the northern margin of the coalfield, the numerous local breaks, the thinning of the beds, and the frequence of sandstones and pebble-beds, indicate the nearness of the shore, inasmuch as in Pembrokeshire the overlapping of the Siluro-Cambrian by Coal-Measures, without the interposition of Viséan, allows of the precise tracing of the shore-line. Central Wales, therefore, was a land connected eastwards with the Mercian Highlands, and westwards, beyond the Viséan Straits of Anglesey, with the South-Eastern Highlands of Ireland (Sollas, Appendix III., No. 56, page 112). In Ireland, too, there is plenty of evidence of the large extension of the Viséan deposits, and only the summits of the highest Caledonian ridges appeared as islands in the Viséan sea.

*Continent.*—On the Continent the Viséan deposits display the same general overstepping. At Visé they rest on Middle Devonian, and in the Campine syncline they have been found in the Kessel boring (south-east of Antwerp) resting on Upper Devonian. Quite recently a trial boring put down at Woensdrecht, Zealand (north of Antwerp), came across Viséan limestone overlain by Coal-Measures. Typical Viséan limestones are to be found as far as Southern Westphalia, where they pass laterally to the Culm-facies. Nowhere on the Continent does the Viséan display the sandy or pebbly rocks so common in the British Isles. But the Viséan limestones show throughout the North-West European belt a wonderful likeness of character and fauna, thus indicating the existence in this belt of an extensive and unbroken sea. It may, therefore, be concluded that the end of the Viséan marks the climax of extension of the Carboniferous deposits.

* For the pebbles containing Tournaisian fossils, the evidence is conclusive.

(2) PHYSIOGRAPHY OF THE UPPER CARBONIFEROUS PERIOD.

As a result of the phenomena described in the foregoing section, the following was the aspect of North-Western Europe on the eve of the Coal-Measure Period. The main Caledonian ridge was still existing as the south-eastern shore of a continent. Southwards an unbroken but shallow sea, with a few islands, stretched up to the Cornwall-Hartz anticline. In the main Caledonian syncline, in Scotland, Ireland, and in North-Eastern England, the formation of coal had already set in. No important phenomena mark the dawn of the Coal-Measure Period, except, perhaps, a general earth-movement, which was doubtless very regular and slow, and resulted in a gentle folding. In some places the upheaval was sufficient to produce local emergencies. The phenomena of coal-formation seemed to come to a standstill, but soon set in again slowly and locally, until at the beginning of the Middle Coal-Measures they took a sudden and marvellous impetus. The difference between the physiographical conditions of the Lower and of the Upper Carboniferous is such as to raise a difficult problem in regard to the causes of this difference. There is an important change in the sediments of both periods, which the above movement is unable to explain, as the Lower Carboniferous sea was nearly always a shallow sea; but the formation of coal makes a still more important contrast. Indeed, coal-deposits exist throughout the geological series of formations; nevertheless, during the Carboniferous Period, coal-formation took place on a scale which has never been equalled since, thus indicating that the Coal-Measure deposits owe their coal-seams to a combination of suitable conditions (Watts, Appendix III., No. 73, page lxxxv.). Among these conditions the writer may quote (1) the neighbourhood of mountain ranges, condensing heavy rains and yielding ample material to erosion and sedimentation. For this purpose the main Hercynian anticline* towards the south, and the main Caledonian anticline towards the north, played an active part in the phenomenon. (2) The enormous thickness of the Coal-Measures, showing throughout a continuous repetition of the same lithological complex, which clearly indicates that subsidence of the earth's crust kept pace with sedimentation in the coal-forming areas. Such concordance may have resulted

* This, the writer believes, was already existing (see page 146).

from the slow and gradual sinking of broad synclines and from the corresponding upheaval of intervening anticlines, both movements producing a general and gentle folding. That such a folding took place during the Coal-Measure Period in North-Western Europe there is abundant evidence to show, this folding being the result of posthumous Caledonian and of precursory Hercynian movements. (3) Peculiar climatic conditions, such as temperature, moisture, rain, and light, seem no less necessary; but perhaps the most powerful factor was the chemical composition of the atmosphere, rich in carbonic acid, yielded by volcanic eruptions (?). As for the difference in the lithological character of the sediments of both divisions of the Carboniferous, it is doubtless the result of an important change in Continental denudation. Limestones are produced during dry and warm periods while the transport of sediment to the sea is unimportant. On the contrary, sandy and clayey sediments are produced during wet periods of active Continental erosion and transport. A good deal of the coarse rocks of the Coal-Measures owe part of their origin to the disintegration of granitic rocks, for granitic pebbles and minerals (felspar and porphyritic quartz) are common in these rocks. There is every reason to trace these constituents to their origin in the Archean and eruptive rocks of the northern and southern boundary of the great Carboniferous belt.

### (1) *The Pendleside Period.*

*North of France and Belgium.*—The study of this division is very easy in these countries, owing to the uniformity of its characters everywhere. Except in the Boulonnais coalfield, Pendleside rocks fringe all the coalfields of the Namur and Dinant synclines. It is not yet known whether they exist in the Campine syncline, except at its eastern end, where they have been found in the Lanaeken boring. They overstep the margin of the Namur Basin (Appendix III., No. 57) and the Middle Devonian of the Visé inlier: the writer has shown that they had formerly a large extension over the intervening anticlines in Belgium (No. 59), and there is no doubt that this period, on the Continent, was a period of subsidence and of deepening of the sea. Arenaceous sediments are represented by exceedingly local and fine-grained sandstone, and by widespread regular beds of black chert (phthanites). Although they have not yet been

studied microscopically, they are so much like the radiolarian cherts of Devon that they are also doubtless radiolarian rocks. The evidence of the fauna as to the physiographical conditions is contradictory, for, on the one hand, we find deep-sea Cephalopoda (*Goniatites*) crowding the shales and limestone nodules, and on the other hand littoral Lamellibranchiata (*Posidonomya*) no less abundant. As other littoral shells are quite uncommon, the writer is inclined to believe that the Lamellibranchiata were drifted to the deep sea, inasmuch as they are often found clinging in clusters to floating plants (Baudour Colliery, Belgium).

*Germany.*—Typical Pendleside rocks of the Belgian facies exist on the right bank of the Rhine (Lintorf), but immediately disappear in the complex Culm Series, where, as in Devon, they still await for minute zoning. It is noteworthy that, on the right bank of the Rhine, between Mayence and the Ruhr coalfield, all the Carboniferous rocks assume the facies of the Culm, and that in many places the Devonian assumes the characters of the Old Red Sandstone, so that there is at both ends of the great belt exactly the same sequence of rocks throughout Devonian and Carboniferous times.

*British Isles.*—Through the exertions of Wheelton Hind, the Pendleside Series is well known in the Midlands; but elsewhere the work of careful zoning still remains to be performed. Nevertheless, it is certain that the sea was much less extensive than in the Viséan period. W. Hind and Howe have published a map (Appendix III., No. 36) showing the area occupied by the Pendleside sea as a long and narrow basin stretching from Central England to Central Ireland. Some addition might be made to this area, for Hind himself recorded typical Pendleside rocks and fauna on the southern margin of the South Wales coalfield, where they present a striking likeness to the contemporaneous strata of Belgium (Appendix III., Nos. 37 and 67, Part VIII., page 22; Part IX., page 18; Part XI., page 170). However, from this map we may gather that the British Isles then began again to show important symptoms of Hercynian longitudinal folding by the formation of a marine syncline in the Midlands between the emerged Wales and Westmorland anticlines. Moreover, while the Wales-Brabant anticline was sinking in Belgium, it was rising in England; and the South Wales-Namur syncline was

submerged in South Wales and Belgium and emerged in Kent* and the Boulonnais. Thus we have evidence also of the early existence of transversal Hercynian folding.

### (2) *The Millstone-Grit Period.*

*British Isles.*—Except in the Midlands, many so-called Millstone-Grit rocks, as Arber (Appendix III., No. 6, page 268) opportunely noticed, are of very different age, and some of them, as, for example, in the Forest-of-Dean, Clee Hills, and Warwickshire coalfields, have already been removed to other divisions. Millstone-Grit rocks seem to have nearly the same extent as, or even a greater one than, the Pendleside Series. From their lithological characters it may be inferred that they were deposited in shallower waters. In all the districts where they have been accurately described, one of their distinctive characters is the great development of grits and pebble-beds built up from granitic material (pebbles, grains of felspar, and granitic or porphyritic quartz) as occurring in the Midlands, South Wales, and Belgium. Beds of such coarse Millstone-Grit rocks cover thousands of square miles, and they afford evidence of the denudation of granitic rocks on an enormous scale. Therefore, the problem of the origin of this granitic material is an important one. In Belgium there is no granitic outcrop round the coalfields; but in England there are some granitic masses near the coalfields. The most important however (those in Devon and Cornwall), are post-Carboniferous. Others, like the Mount Sorrel granite, are of a hornblendic type not yet recorded in the Coal-Measure conglomerates. As granite is a deep-seated rock, many granitic dykes were not yet laid bare and exposed to denudation. The granites of Wicklow and of the Lake District seem to have been the only possible sources of the granitic pebbles and sediments composing the Millstone Grit of the Midland and South Wales synclines. But, from their limited surface, they were likely unable to yield the enormous amount of granitic material supposed to exist in the thickness of the Coal-Measures. We are therefore compelled to look for a more distant origin, and to go as far as the Archæan rocks and granitic outcrops of the boundaries of the great Carboniferous belt. Likewise, from a careful

* Pendleside rocks are wanting in Kent (see Arber, Appendix III., No. 8, page 34), and in the Boulonnais (No. 33).

study of the origin of the Millstone-Grit constituents of Yorkshire, Gilligan (Appendix III., No. 30) was induced to suggest a Scandinavian origin for some pebbles in this rock, and pointed out the likeness of some Millstone-Grit rocks to the Torridonian Sandstone. It is thus highly probable that they are built up entirely at the expense of the same parent rocks. For the pebbles and minerals to travel from one syncline to the other, large and open connexions between them were necessary.

*Continent.*—In the North of France the Millstone Grit does not extend to the western end of the coalfield, and therefore the Kent-Boulonnais transversal anticline was still existing. In Belgium the conglomerate of the Millstone Grit (Poudingue houiller) is largely composed of pebbles from the Pendleside Series and from the lower beds of the Millstone Grit itself. Thus it may be inferred that the intervening anticlines had already begun to rise and to expose their blanket of Carboniferous rocks to denudation (Stainier, Appendix III., No. 59) when this top bed was forming. As for the granitic material of this bed and others similar in the Coal-Measures, the writer has shown in the paper just cited that the source must be looked for towards granitic rocks now buried under the sediments of the Paris Basin. In Westphalia the contemporaneous "Flötzleerer Sandstein" is still *terra incognita* from every standpoint.

### (3) *The Lower Coal-Measure Period.*

In Appendix II. the writer exposes the grounds on which he drew this division, but this is a much-vexed question, and, as the work of classifying and zoning the strata of this division is still unimpaired in many coalfields, the writer is prevented from dwelling on this subject. From a lithological as well as from a geographical standpoint this division is more closely related to the Millstone Grit than to the Coal-Measures, as no great change intervenes between them.

### (4) *The Middle Coal-Measure Period.*

This is really the period of coal-formation during which all the favourable conditions prevailed. Important geographical changes took place, the leading features of the future Hercynian folds began to assume shape, and the writer will point out some of them.

*Westmorland Anticline.*—From the existence of the Ingleton coalfield in the very middle of this anticline, one might suppose that Middle Coal-Measures formerly extended all over it. But recent researches show that this could hardly have been the case. From the study of borings put down in this coalfield Walcot Gibson (Appendix III., No. 28) believes that the red measures capping this coalfield are conformable with the Middle Coal-Measures below, since there is a gradual transition from one to another. In these Middle Coal-Measures Dr. Arber (Appendix III., No. 5) detected *Dictyopteris sub-Brongniarti*, a plant which characterizes the top of the Middle Coal-Measures. These red measures might, therefore, belong to the Transition Coal-Measures, and the Lower Middle Coal-Measures and Lower Coal-Measures should be wanting* on the top of the anticline, an indication that during the formation of these divisions the anticline had emerged. If further researches should give ground to this supposition, the history of the Ingleton coalfield would be nearly the same as that of some Midland coalfields (South Staffordshire).

*Midland Syncline.*—In the meantime this syncline was slowly undergoing the subsidence already observed during the foregoing periods, and, owing to this phenomenon, the overlapping of the Mercian Highlands made further progress. Prof. C. Lapworth (Appendix III., No. 2, Part IX., page 5) has shown how, on the southern margin of the Midland coalfield each division is, in turn, overlapped by the following one, until at last the Upper Measures came to rest near or over the top of these highlands, hiding their rugged floor under a blanket of Coal-Measure rocks. Considering the uneven surface upon which they were deposited, the irregularities of shape and thickness of the South Midland coalfields can be understood, as also the varying thickness of the coal-seams, the protruding bosses of older rocks, and the various ages of their strata. Jukes long ago pointed out how the peculiar characters of the most typical of these coalfields, the South Staffordshire fields, accord with their peculiar geographical conditions. It was but a little while before the end of the period that the southernmost coalfields were covered by Middle Coal-Measures, and it is quite probable that, at least along the Welsh

* A different opinion is expressed by Dr. A. Strahan (Appendix III., No. 65, page 2), who traces the break lower down in the Coal-Measures. At any rate, there is a break.

Borderland, the Middle Coal-Measures never crossed the Wales anticline,* for along the Malvernian axis there is a row of inliers of Upper or Transition Coal-Measures resting on older rocks without any interposition of Middle Measures. The Middle Measures of the Titterstone Clee Hills according to their characteristics (Arber, Appendix, No. 7, page 420) belong to the Midland type. Therefore the Shropshire plateau, the slope of which was dipping southwards during the Tournaisian,* became inclined northwards since the Viséan period.

Among the many questions relating to the geological history of the Midland coalfields the writer will deal with the relationship existing between the various portions of the main coalfield. On first consideration such irregularity seems to prevail among the Southern Midland coalfields, with respect to their distribution, shape, outlines, and thickness, that one might believe they were always independent, inasmuch as different types of rocks are to be found in these basins. Moreover, optimistic views, with regard to their underground connexions, have at times been upset by recent researches. Nevertheless, they possess such a similarity of important characters that there is ground to believe in their original connexion. In this respect the writer may point out that (1) nearly all these coalfields present the same marine beds with the same fauna. According to the life-conditions of marine beings, they cannot migrate from basin to basin except by sea communication. This is especially so for pelagic animals, such as Cephalopoda and Encrinites (the former being conspicuously abundant in these marine-beds). Marine fossils have been detected in the Middle Measures of the coalfields of Leicestershire, Warwickshire, South Staffordshire, and Coalbrookdale, and they are still more plentiful in all the coalfields round the Central Pennine Chain. Marine fossils have not yet been detected in the Wyre Forest coalfield, due, probably, to lack of research, for Dixon (Appendix III., No. 23, page 611) discovered *Productus* in these measures in the Clee Hills, and marine fauna could not reach the Clee Hills from the main basin except through the Wyre Forest.

(2) Mussel-bands, or beds crowded with shells of the family of Carbonicolidæ, are plentiful in many of these coalfields.

* We have no actual evidence that, in other parts of this anticline, in England, the Middle Measures never crossed it.

Although the evidence afforded by the presence of such fresh-water or brackish shells is not of prime importance, nevertheless it may be imagined that such shells living in quiet and muddy waters would be unable to cross land, especially when no flying vertebrates existed to carry their spawn.

(3) As for the differences between the sediments of some coal-fields, they are not of such a kind as to render a common origin inadmissible. Geologists who have had the opportunity of mapping coalfields are acquainted with the differences that they always display owing to sundry local conditions, but by a minute survey it is often possible to trace the gradual passage from one sediment to the other.

(4) The more-or-less detached condition presented nowadays by these coalfields is not in itself evidence that they were always so detached. Everybody knows that the Coal-Measures, after the upheaval of the Hercynian range, were exposed, especially the topmost beds, to the denudation which follows the building-up of a mountain range. Such inliers as the Clee Hills coalfields, standing as landmarks on the Shropshire platform, afford classical examples of erosion witnesses (*temoins d'érosion*). The absence of Upper Measures in these hills has often been alluded to, while they are well represented in the next coalfield. It is easy to see that these hills owe their existence to a cap of hard eruptive rock, which prevented the underlying strata from being swept away like the overlying Upper Measures and the surrounding Middle Measures which were unprotected by such a cap. There is, therefore, good reason to believe that the Midland coalfields are parts of a former larger coalfield.

*North Wales-Brabant Anticline.*— While its northern margin was sinking, in the Midlands, there is ground to believe that its southern margin, according to locality, was either sinking without other motion, or slightly rising. In Belgium it was rising, and by erosion getting rid of its cover of Carboniferous rocks, which the writer found as pebbles in the conglomerates and in the coal-seams of the Middle Coal-Measures; while in the Transition Measures the erosion laid bare the old Siluro-Cambrian floor, which yielded pebbles and grains for the conglomerate of Noeux (Barrois, Appendix III., No. 9; Stainier, No. 59). Likewise in South Wales pebbles of cannel-coal, ironstone, anthracite, and conglomerate were found in coal-seams well up

in the Coal-Measures by Logan, Strahan, and De le Beche. These facts show that the Lower Measures have been subjected to upheaval and denudation on the rising anticline. On the contrary, the conspicuous overlapping of the Middle Coal-Measures in North Pembrokeshire gives clear evidence of the gradual sinking of the anticline in that district. Similarly in the Pas-de-Calais coalfield there is a gradual overlapping north-westwards of each division of the Middle Coal-Measures, until finally in the Boulonnais coalfield very high measures came to rest on the Viséan.

*South Wales-Namur Syncline.*—The most important event in the history of this syncline is its invasion by the Middle Measures in Kent. But we are still unaware as to their extent and relationship with the surrounding strata. Except on both sides of the Dover Straits and for some parts of the Pendleside and Millstone-Grit Series in South-West England, the writer believes that there is a continuous sequence, in this syncline, from the top of the Viséan to the Transition Measures. In Eastern Westphalia, on the Upper Lippe, the Middle Coal-Measures have been found, in borings, overstepping the Middle Devonian.

*The Devon-Dinant Syncline.*—In Devon and Cornwall the correlation of the Carboniferous rocks have been much obscured by Hercynian disturbances, while in the Dinant basin the strata have been so deeply eroded that we are unable to draw any useful conclusion from the structure of both of these areas.

(5) *The Transition and Upper Coal-Measure Period.*

Noteworthy earth-movements mark the end of the foregoing period. The formation of coal went on unchanged in some areas (France and Belgium), while in other areas (South Midlands) it went on slowly, or even stopped.

*Great Britain.*—The most interesting movement of which there is evidence is the folding which gave rise to the so-called "Symon" Fault of the Coalbrookdale coalfield, for, thanks to the exhaustive study of Clarke (Appendix III., No. 16), we have valuable information regarding it. Between the Middle and the Transition Measures a gentle folding took place along the Shrop-

shire Borderland, giving rise to a series of folds striking north-east and south-west, which increase in importance towards the north-west. The north-western wing of the synclines has a steeper dip than the south-eastern wing. This is clear evidence that the folding is a posthumous Caledonian movement originating in the north-west. The results of this folding seem to have been felt as far as South Staffordshire and Warwickshire, but with features showing a diminishing energy eastwards. In the former coalfield Dr. R. Kidston recorded an unconformity between the Middle and the Transition Measures, where, moreover, the Etruria Marls are wanting (Appendix III., No. 45). Likewise, R. D. Vernon (No. 71, pages 598-600) has shown that the Etruria Marls (Nuneaton Clays) are locally wanting between the Transition and the Middle Measures in the Warwickshire coalfield. Round the Pennine Chain there is a conformable sequence everywhere, according to Dr. W. Gibson (Appendix III., No. 26, page 264). In the Cumberland coalfield an unconformity is also supposed to exist on the top of the Middle Coal-Measures (Arber, Appendix III., No. 3). But the question seems to be controversial. In the Ayrshire coalfield the unconformity which was supposed to exist between the productive measures and the Upper Red Measures has been shown recently to be much less important.* After this folding general subsidence took place in the British Isles, especially along the Wales anticline. The Welsh Uplands and the Mercian Highlands were overlapped by the Transition and Upper Measures. A row of small inliers of these measures, starting from the Wyre Forest coalfield, may be seen along the Malvernian range, either between the protruding detached pieces of the range, or even on its summit (Woodbury Hill). The last member of this row is the Newent coalfield, the characteristics of which, according to Dr. Arber (Appendix III., No. 4), are more closely related to the Shropshire coalfields than to the southern coalfields. Therefore we may suppose that a barrier existed south of the Newent coalfield, and this barrier was doubtless the North Wales-Woolhope anticline and its prolongation through May Hill. During a long period this anticline played an important part in the history of this district. Its upheaval is doubtless post-Devonian, for the disseverance of

*Summary of Progress of the Geological Survey, 1901, page 3.

the Upper Old Red Sandstone of the Clee Hills from the strata of the same age in Gloucestershire and Glamorganshire was produced by this upheaval. The writer believes that the true age of this upheaval is Tournaisian, its slow rise compelling the southward retreat of the Tournaisian sea previously mentioned (Fig. 1). From the great difference of sediments and sequences on both sides of this anticline there is conclusive evidence of its continuous existence throughout the Upper Coal-Measure Period, and that it was never covered by deposits of this age. In the Kent coalfield Transition Measures are fairly well developed (Arber, Appendix III., No. 8); but there are few indications regarding their extent or their relationship with other strata. In South-Western England an important overlapping took place, for in the short distance separating the South Wales and Bristol coalfields from the Forest-of-Dean coalfield, the Upper Coal-Measures overstep the whole thickness of strata from the bottom of the Viséan up to the Upper Measures. Moreover, all the measures of the Forest-of-Dean coalfield belong to the Upper Coal-Measures, as pointed out long ago by H. De la Beche (Appendix III., No. 20, page 203) and confirmed by Dr. Arber (No. 6, page 277), and they rest unconformably on Lower Carboniferous sandstone (Sibly, No. 55). Therefore the southern as well as the northern margin of the Wales anticline was sinking during this period.

The writer has already dealt with the possibility of the extension of Transition or Upper Coal-Measures above the Westmorland anticline;* but he is unable to trace the history of the Northumberland-Cumberland syncline during this period. In Northumberland the Upper Red Measures have not yet been submitted to modern palæontographical and stratigraphical study, while in Cumberland and in the Canonbie coalfield much obscurity still prevails regarding some important points. Large sheets of unmetamorphosed and loose Upper Coal-Measures were disturbed and uplifted by the Hercynian folding, and afterwards exposed to denudation and swept away. The evidences of overstepping displayed by the Upper Measures afford ground also to believe that, at the end of the period, England was covered with deposits which were not so extensive as the Viséan formation, but were, nevertheless, very important. The Transition and

* See page 114.

Upper Coal-Measures of England display two very distinct types, which one may designate as the South Wales and the Midland types. The South Wales type developed in the South Wales-Namur syncline, and (except for a bed of red shales in the Bristol coalfield) is the normal type of productive Coal-Measures, with a marked predominance of arenaceous sediments (Pennant Grit) in the lower part. The Midland type presents the following features:—(1) A predominance of red and greenish (Espley rocks) sediments; (2) occasional beds of conglomerates and breccias; (3) coal-seams scarce, thin, and often yielding sulphurous coal; and (4) occasional, but not uncommon, thin beds of *Spirorbis* limestone. All these characteristics indicate very peculiar physiographical conditions during this period, which it is by no means easy to explain. The presence of red rocks may be ascribed, as in other red-rock formations (Permian, Trias, etc.), to climatic influences, such as desert conditions, and extreme changes of temperatures. The presence of breccias should give some support to this hypothesis (Bonney, Appendix III., No. 14); but the writer cannot reconcile the existence of desertic conditions and extreme temperatures in Shropshire and South Staffordshire with the fact that a typical and rich Coal-Measure flora flourished near by, as in the Forest of Dean, Bristol, and Manchester.* Moreover, this abnormal type is exemplified by the Middle Coal-Measures of the Clee Hills and Wyre Forest coalfields (Arber, Appendix III., No. 7, page 420). Red measures also exist in the Millstone Grit of some coalfields (North Staffordshire, W. Gibson, Appendix III., No. 27); but it is a curious fact, and not a mere coincidence, that red measures are also often very barren measures. In the Midlands the red colour of the sediments may perhaps be ascribed to the abundance of volcanic detrital material, some beds showing under the microscope a great deal of volcanic material (W. Gibson, Appendix III., No. 26, page 265). But what then of the breccias? It must be admitted that an explanation of these abnormal characters is still to be found.

*Continent.*—The writer has already spoken of the overstepping of the Transition Measures of Northern France. In Bel-

*In the Manchester coalfield (Bradford-Ardwick) the lower part of the Transition Measures is productive and of normal type (Kidston, Appendix III., No. 46, and Gerrard, No. 31).

gium there are many hundred yards of strata on the top of the Hainaut coalfield still awaiting the determination of their age, and there is little doubt that these beds are coeval with the Transition Measures of the North of France. In both countries they are productive, and of the South Wales type. In Belgium the upper beds do not display any sign of overlap. Likewise the age of the uppermost beds discovered in Westphalia, by the last borings, is still unknown. On the supposed northern margin of this coalfield, Upper Coal-Measures crop out in small inliers near Osnabrück. Also the coal contains a low percentage of volatile matter; often it does not exceed 7 per cent., and we may therefore infer that the older Coal-Measure divisions are wanting below, and that these Upper Measures overstep a still unknown pre-Carboniferous floor. In the Saarbrück coalfield the conditions are quite different from any other part of the great Carboniferous belt, for a conformable sequence from higher divisions in the Permian to lower divisions in the Middle Coal-Measures occurs, resting probably on Lower Devonian rocks.

## Part II.—Denudation of the Coalfields.

It is unfortunately very difficult to obtain an exact knowledge regarding the denudation undergone by the coalfields after their formation, although such a knowledge is essential in order to trace the actual extent of the coalfields. We have no tangible means of ascertaining the activity of denudation, especially of subaërial denudation in the past. From the study of denudated countries we only know that the denudation is especially powerful on the anticlines, upheaved and disturbed strata, and that the Coal-Measures lying in regular synclines were much more likely to be preserved. A thorough knowledge of the tectonics of a country and of the inroads of the sea affords therefore the best means of studying the denudations. As the phenomena of erosion were already at work during the formation of the coalfields, and are still active to-day, the subject is so extensive that the writer feels compelled to content himself with a short sketch of the periods following immediately the Coal-Measures during which these phenomena were most active.

### (1) *Stephanian Period.*

This division has been introduced in the geological chronology by the French geologists, but it may be questioned whether

this period does not coincide more or less with the Upper Coal-Measure Period of English geologists. A careful comparison of the Upper Coal-Measure flora of England with the flora of the Saarbrück and the Central French coalfields should settle the problem, but has not hitherto been attempted. The writer will not dwell on this problem, which is really far beyond the scope of this paper. One thing seems to be quite certain, that the main upheaval of the Hercyian range took place after the deposition of the Upper Coal-Measures and before that of the Lower Permian (Rothliegende). We may regard the Stephanian Period, at least, as the period of the building-up of this mountain range. As a brief summary of the foregoing periods, we may say that after many attempts at upheaval, the leading Hercynian anticlines had nearly disappeared in the British Isles. Some Charnian anticlines had slightly emerged in the South of England, while the Caledonian Highlands were still standing much worn and lowered, overlooking the ruins of the Dumfriesshire anticline. On the Continent the Brabant anticline had perhaps emerged, the Hartz anticline still more, and the main Hercynian ridge was already built up.* During the upheaval of the Hercynian range the anticlines and synclines (a list of which has already been given) were built up, some of them as new features, others rejuvenated or blocked-out old tectonic unities, while others were modified, derived, or readapted structures. For a while North-Western Europe became a mountain range, in which at last, under the impulse of a pressure from the south, a giant thrust-plane originated, stretching from the Rhine to Ireland, along the Mendip-Condroz anticline, which was built up with accumulated overthrusted masses. The geological structure exhibited by the geological map of the North-Western European Palæozoic deposits is, to a great extent, the result of these powerful earth-movements.

### (2) *Post-Carboniferous Periods.*

The history of the ruin of the Hercynian range is the textual repetition of that of the disappearance of the Caledonian range. After each, the same succession of physiographical conditions is found. In the Lower Permian we have the repetition of the Old Red Sandstone conditions. In the Magnesian

* See page 146.

Limestone sea we see the return of the Carboniferous Limestone sea. The Bunter pebble-beds remind one of the Millstone-Grit conglomerates, and the Keuper Sandstones and Marls remind us of the Coal-Measures. There is one striking difference, namely, the absence of coal in the Keuper, which looks like the Upper Coal-Measures of the Midlands. Any formation of coal was prevented by the desertic conditions prevailing during the period (J. G. Goodchild, Appendix III., No. 32), but coal-deposits of Keuper age exist in Germany (Kohlen-Keuper) and elsewhere.

*Lower Permian Period.*—One or two freshwater lakes originated in the districts of the late Carboniferous basin, which were the most remote (Appendix III., No. 39) from the Hercynian ridges and on the deepest or western wing of the Pennine Chain. The sediments of these lakes overstep with unconformity the slightly-disturbed Coal-Measures or the older rocks laid bare by denudation. These lakes were soon filled up by water courses eroding the surrounding ridges. The harder and metamorphosed older rocks yielded pebbles for the thick Permian breccias and conglomerates, while the loose, yet unmetamorphosed, Coal-Measures were responsible for the formation of sandstones and marls.

*Upper Permian Period.*—The subsidence on an enormous scale of large parts of the Hercynian range allowed of the formation of a big inland sea,* the Zechstein sea, which stretched as far as the slopes of the Thüringerwald, of the Hartz, of the Wales-Brabant anticline, and of the Pennine Chain, and into the bays between these uplands. In these bays extensive salt-deposits were afterwards concentrated when they became land-locked basins (Stassfurth, Hanover, Lower Rhine, Holland, and Durham). Through some sunken passes of the Pennine Chain, this sea was able to invade the Lancastrian Permian lake as far as Ireland, for above the Lower Permian there are traces of Magnesian Limestone and Zechstein fossils in this lake.

*Bunter Period.*—While the foregoing period was essentially, because of the dry climate, a period of chemical sedimentation, the Bunter was again a period of activity in mechanical denudation, and a proof of this is the thickness and extent of

* This sea Ramsay compared with the modern Caspian Sea.

the pebble-beds. During the period also transversal or longitudinal subsidence (*Graben*-formation) was very important, and many unimportant Hercynian ridges were cut to pieces.

*Keuper Period.*—Sedimentation, often chemical (gypsum and salt), filled, during this period, the deep basins originated by continuous subsidence, and at the expense of surrounding ridges. Denudation was very active, with the help of peculiar desertic conditions. During the foregoing periods, earth-movements took place, which, though on a much smaller scale than the foregoing, were by no means unimportant. Folding and faulting went on, followed by denudation. Through these posthumous disturbances, the tectonic net of North-Western Europe, already very complicated, became still more so by features of less importance. As a general result of these post-Carboniferous phenomena, the great North-Western European belt was separated into detached basins, and the old core of the intervening anticlines was laid bare. It may be added that, from the Keuper Period up to the present, folding and faulting, erosion and sedimentation, have never ceased to work on the Palæozoic floor of North-Western Europe. The important faults of the Wurm and Dutch Limburg coalfield are still shaking the ground (Herzogenrath earthquakes). Beneath the plains of Holland and the Campine the Coal-Measures are buried low down in the earth's crust. The Molembeersel boring was still in the Oligocene at the depth of 3,442 feet in the Campine (Stainier, Appendix III., No. 61). At the Rothem boring the Coal-Measures were found at the depth of about 4,000 feet.

## Part III.—Local Descriptions.

Theoretically, the problem of tracing the relationship between detached coalfields is a simple one. One has first to trace the original extent of these coalfields, and afterwards to observe the modifications that they underwent in course of time. In the foregoing pages the writer has given only the general notions regarding the problem, and yet one may note how complicated it is in practice. In order to put the complexity of the problem in a fuller light, the writer will make a more minute study of some parts of the great Carboniferous belt of North-Western Europe. These parts he will choose in England, as they are, doubtless, much more complicated and interesting than on the

Continent, where the sharp Hercynian folds mask all other phenomena.

### (1) *The Malvernian Range.*

This miniature mountain is very interesting, as it exhibits, on a small scale, all the features of a great range. Moreover, it is the only anticline that may be followed from the South Wales up to the Midland synclines, and it is, therefore, a good type of transversal anticline. From the papers published by John Phillips (Appendix III., No. 51), Morgan and Reynolds (No. 49), A. Strahan (No. 63), T. Groom (Nos. 34 and 35), Sibly (No. 55), Dr. Arber (Nos. 6 and 7), and T. Cantrill (No. 15), one may grasp the particulars of the five detached inliers of this range.

(1) *Tortworth Inlier.*—This is a *massif* of Silurian rocks, showing a double anticline conformably flanked by Lower Old Red Sandstone on the west, and with Upper Old Red resting, in apparent conformity, in the median syncline. At its southern end both anticlines diverge in order to embrace the Bristol coalfield. The eastern anticline, striking south-south-eastwards, soon disappears under the Mesozoic strata, but the western anticline, after a further bifurcation, may be followed on the western side of the Nailsea coalfield up to Steepholm,* where it comes into touch with the Mendip anticline. By its rupture into three diverging anticlines the Malvernian range has a wide base resting on the Mendip anticline from Steepholm to Frome.

(2) *May Hill.*—This is a more complicated anticline of Silurian rocks, with a north-to-south trend. But near its northern end a north-west to south-east fold is superimposed upon it, which beyond any doubt is the prolongation of the longer axis of the neighbouring Woolhope anticline crossing the Malvernian range.

(3) *Malverns.*—The structure of the Malverns, which has been thoroughly studied by Dr. T. Groom, is very disturbed and complicated, especially in the Southern Malverns, where doubtless the range had its apex. A long eastern *massif* of Archæan age has been thrust over the Cambrian and Silurian of the western margin. Thrust-faults are numerous, dipping eastwards on the eastern margin and westwards on the western mar-

* See Fig. 3. Steepholm, with its anticline striking east-north-eastwards, belongs to the Malvernian range, while the folds of Flatholm striking east-south-eastwards belong to the Mendips (Appendix III., No. 74, page ccxiii.).

gin. The general trend is north to south, but at the southern end through a "fenêtre" in the thrust-plane a piece of an old north-west to south-east Charnian fold appears (Coal Hill). According to Dr. Groom (Appendix III., No. 34), the structure of this part of the range is the result of deep and narrow folds afterwards broken by deep and nearly vertical thrust-faults. The northern end of the Malverns is more regular, with a general north-to-south trend and an isoclinal (overfolded) structure, all the strata dipping eastwards. Here, again, the eastern margin has been thrust over the western margin along the planes of thrust-faults, with a slight dip eastwards. The Malverns display the most convincing evidence of the existence of an impulse from the east. The westward dip in the Southern Malverns is doubtless the result of the neighbourhood of the Woolhope anticline acting as an obstacle during the westward march of the thrust massives.

(4) *Abberley Hills.*—These hills present exactly the same structure as the northern end of the Malverns and the same north-to-south trend up to Abberley, where the folds bend north-north-eastwards. Then the axis pitches northwards and disappears beneath a transverse Coal-Measure syncline.

(5) *Trimpley Anticline.*—Mr. T. C. Cantrill has pointed out that this anticline soon reappears in the oval anticline of Trimpley striking north-north-eastwards. This is an inlier of Lower Old Red Sandstone, with a Silurian core, overfolded and thrust westwards over the Coal-Measures of Wyre Forest. Northwards it disappears under the Mesozoic formations.

From the foregoing particulars we may infer that the range presents the following general characters:—(1) A general north-and-south trend except in the north, where it comes into touch with the north-east to south-west Caledonian folds of the Welsh anticline; and (2) an eastern origin for the direction of impulse.

*Age of the Range.*—As in every mountain, the age of this range is very complex, and it received the impulse of many earth-movements before attaining its actual structure. Regardless of previous upheavals, the range was uplifted before the Upper Silurian, which rests unconformably on the Cambrian. It was uplifted, at least in the Tortworth inlier, between the Lower and the Upper Old Red Sandstone (Appendix III., No. 51, pages 19 and 197), and it was again uplifted along the course of the Wool-

hope anticline after the Tournaisian.* Dr. T. Groom is of opinion that its main upheaval took place between the Middle and the Transition Coal-Measures.

The writer has already recorded earth-movements of this age, and it would be very interesting to demonstrate that a movement of the importance of the Malvernian folding is of this age. But this hypothesis is not, in the writer's opinion, supported by facts. Here are the data upon which Dr. Groom grounds his opinion:—(1) The Symon Fault gives evidence of Middle Coal-Measure foldings; (2) Upper Coal-Measures rest unconformably on older formations; and (3) Upper Coal-Measures rest unconformably and undisturbed upon the edges of disturbed strata of the range.

Of these evidences the first two are irrelevant. From Clarke's study respecting the Symon Fault, it is easy to grasp that this disturbance has nothing to do with the folding of the Malvernian range.† As for the unconformity of the Upper Measures, he (Dr. Groom) gives no evidence, unless he demonstrated that these measures do not share in the disturbance of the underlying rocks. Therefore, the third piece of evidence alone is noteworthy. The only section quoted is that of Woodbury Hill, showing Upper (Transition) Measures, horizontal or nearly so, resting on overfolded Silurian rocks (Appendix III., No. 35, page 174, and Fig. 27; and No. 15, Plate I.). But from the papers of Groom and Cantrill it is easy to detect that their section is diagrammatic, owing to the bad condition of the outcrops. Moreover, this section cannot be reconciled with Murchison's description quoting these measures as disturbed.

As the question of the age of the range is an important one, the writer will give hereafter convincing evidence that the main upheaval of the range is posterior even to the Upper Coal-Measures, and as it is not contested that it is pre-Permian, it ought to be Stephanian:— (1) From the sections of the Trimpley anticline given by Cantrill (Appendix III., No. 15, Plate I.) it is evident that the Transition Measures of the Shatterford Pit, and even the neighbouring Upper Coal-Measures (so-called Lower Permian), share in the overfolding and overthrust of the Trimpley anticline. (2) The section across Woodbury Hill and the southernmost tongue of the Wyre Forest coalfield drawn by Dr.

* See pages 105 and 118. † See page 117.

Groom (Appendix III., No. 35, Fig. 27, page 174) gives absolute evidence that this tongue is involved in the overfolding of the Abberley Hills. Still, this tongue is a part of the Transition Measures of the Mamble division of the Wyre Forest (Arber, Appendix III., No. 7, page 367). (3) The section of the Newent coalfield, which is of Transition age (Arber, Appendix III., No. 4), given by J. Phillips (No. 51, pages 7, 104, and 109) represents the strata dipping eastwards as much as 45 degrees. (4) The Upper Coal-Measures of the Forest of Dean (Arber, No. 6) are involved in the upheaval of May Hill, and their eastern margin is dipping westwards at high angles. (5) The Upper and Transition Measures of the Bristol coalfield share in the syncline of the Tortworth inlier. Therefore, the whole range is beyond any doubt mainly of post-Upper Coal-Measure age.

### (2) *The Usk Anticline.*

The oval Usk anticline (Monmouthshire) has a north-to-south longer axis, and is built up of minor folds striking north and south. The Upper Coal-Measures of the South Wales coalfield share in its anticlinal structure. Therefore, it is of the same age, it has the same trend as the Malvernian range, and it may be regarded as a minor ridge allied to this range.

### (3) *The Pennine Chain.*

For the sake of convenience the writer will draw three divisions in the chain, namely:—

(1) *Central Division.*—This is the well-known Pennine Chain, stretching from Ashbourne to Skipton. It is a typical anticlinorium uplifted by an impulse from the east (Gibson, Appendix III., No. 29, page 38). As a result of this unilateral pressure, it displays, in a cross-section, a dissymetrical structure, which is a common characteristic in mountains. Its eastern wing is regular, with a gentle eastward dip, while the western wing is steeper and more disturbed by faults and fringed by a deeper syncline. Standing in the very centre of one of the most extensive Hercynian synclines, free from Caledonian disturbances, its trend is nearly north to south, but at its northern end it bends slightly north-north-westwards, and at its southern end it bends slightly south-south-eastwards.

(2) *Northern Division.*—In this division the chain has lost most of its classical characteristics, and for some length even loses its anticlinal structure. Therefore, geologists of no little authority believe that the disturbances of this division are independent of the Pennine Chain. But it must always be remembered that transverse folds, more so than any other, are liable to change and to lose their character (Appendix I.).* North of Skipton the anticlinal disposition of the chain disappears for a while, for here it comes across the pre-existing longitudinal fold of Pendle Hill, and all the folds between the Lancashire coalfield and the Lake District display a north-easterly Caledonian trend, although, as pointed out by Dr. A. Strahan (Appendix III., No. 63, page 535), they are folds of the Hercynian Westmorland anticline, doubtless because they are superimposed on old Caledonian folds, rejuvenated by the Hercynian folding. Prof. Edward Hull (Appendix III., No. 38, page 323) has shown by an intuitive diagram how the folds north of the Lancashire coalfield gradually lose their east-and-west Hercynian trend towards the west and north, and assume a north-easterly to south-westerly Caledonian trend. On the eastern wing of the Pennine Chain in North Yorkshire there is a continuous succession of small folds, the axes of which trend north-eastwards, such as the Harrogate anticline (Clifton Ward, Appendix III., No. 1, Vol. II., page 505). The Wharfe anticline alone has an east-to-west trend. Wherever the Pennine Chain is free of these cross-anticlines, it reappears as a monoclinal faulted and overthrust structure. Here again one finds the distinctive features of the chain, namely, pressure from the east; an eastern wing with a gentle slope; and a disturbed western wing bordering a deeper syncline. These characteristics are emphasized by (1) the gentle and regular dip of the Yoredale rocks of North Yorkshire; (2) the existence of the Ingleton coalfield; and (3) the Craven and Dent faults. The existence of an eastern impulse is clearly demonstrated by the overthrust of the Ingleborough *massif* from the east and the north-east over the Ingleton coalfield.†

*Page 145.

†The overthrust character of the Craven Fault has been pointed out by Dr. J. E. Marr (Appendix III., No. 48, page 352) and by Prof. J. Garwood (No. 25, page 480).

The intensity of the pressure is illustrated by the structure of the southern margin of the Lake District between Kirkby Lonsdale and Dalton-in-Furness. This district, which has recently been thoroughly studied by Prof. J. Garwood (Appendix III., No. 25), is built up of faulted masses elongated from north to south, and bounded by steep north-and-south thrust-faults. A diagrammatic cross-section, drawn according to his sections, displays the structure shown in Fig. 2, in which the pressure from the east is clearly visible.

Such has been the influence of the Pennine eastern pressure, that the strata of the southern margin of the Lake District underwent curious effects. North of Lancaster, near Halton Green, the folds of Carboniferous Limestone striking north-east gradually bend northwards, until they assume a north-and-south trend, and all the strata of the Kendal and Ravenstondale dis-

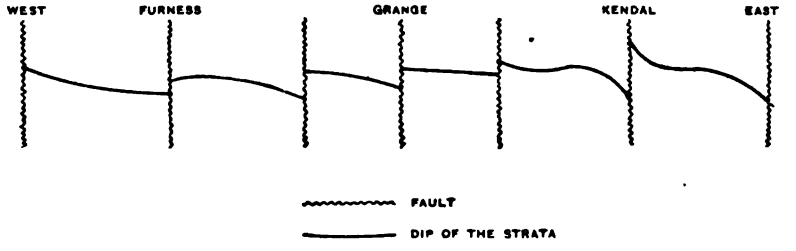


FIG. 2.—DIAGRAMMATIC CROSS-SECTION OF FAULTED MASSES OF THE SOUTHERN MARGIN OF THE LAKE DISTRICT.

tricts have been compelled to adapt themselves to this new structure. The last-mentioned district, by its advanced position towards the east, has been especially disturbed, and one may learn from the map published by Miss Watney and Miss Welch (Appendix III., No. 72, Plate XII.) how a country adapts itself by intense faulting to new conditions. The Pennine Chain near Brough meets with two old Caledonian structures, which it is compelled to follow—(1) the Vale of Eden, a Caledonian syncline rejuvenated by the Pennine upheaval (Watts, Appendix III., No. 73, page lxxxi.); and (2) a ridge already existing before the Carboniferous Period on the site of the Pennine Chain (J. Garwood, No. 25, page 554). While running along this ridge the Pennine Chain loses its own trend to take the Charnian trend of the ridge, and it is very noteworthy that the Pennine Chain all along the north-eastern margin of the Lake District is broken

on its western wing by the Pennine Fault. The writer believes this to be an overthrust fault, and along this part of its course the Pennine Chain again assumes its typical structure of a straight anticline bounded westwards by the Pennine Fault and the trough of the Vale of Eden, and eastwards by the gentle slope leading to the Durham coalfield.

From the north-eastern angle of the Vale of Eden the Pennine anticline strikes north-north-westwards and northwards, and considerably enlarged (like the Malvernian range near the Mendips) crosses the Dumfriesshire anticline. In the sharp folds of this powerful anticline, the transverse structure of the Pennine anticline is difficult to detect. But the writer believes that it is represented by the culminating part of this anticline assuming the character of a broad anticline between the trough or transverse valley previously mentioned in Berwickshire,* still existing in the Old Red Sandstone, and the trough of Nithsdale, still existing in Lower Carboniferous times (Jukes-Browne, Appendix III., No. 44, page 82). The sharp and numerous folds of Lower Silurian rocks south-east of the Hart Fell show the dissymmetrically placed core of this broad anticline. The transverse anticlines crossing the main syncline of Scotland are perhaps the results of the splitting of the Pennine anticline in its passage through this syncline. The folds of the Old Red Sandstone of Caithness described by Peach and Crampton (Appendix III., No. 18, page 112) present, in their trend and dissymetry, all the characters of the Pennine folds, and they may be the northernmost symptom of the Pennine Chain. In the main syncline of Scotland, the north-westerly to south-easterly syncline of the Ayrshire coalfield is beyond any doubt the prolongation of the troughs of the Nith and Eden Valleys† stretching as far as the Coal-Measure inliers of Bute.

(3) *Southern Division.*—The characters, extent, and importance of the Pennine Chain in this division are much more obscure, and are such that the existence of the chain may be, and has been, questioned. But its prolongation in this division has already been pointed out by Prof. C. Lapworth (Appendix III., No. 2, Part IX., page 6) and by Dr. A. Strahan (No. 63, page

*See page 107.

† The straight and continuous trough running from Brough to Bute along the Vale of Eden, Nithsdale, and the Ayrshire coalfield is the most conspicuous transverse feature of Northern Great Britain.

536). The writer will endeavour to trace its course a little further on. Except in the Southern Midlands, the data are scanty, and we must rely on theoretical considerations. The best method seems to be to proceed by way of comparison with the other divisions of the chain and with other allied ranges.*

South of Ashbourne the Pennine axis pitches abruptly southwards, and disappears for a while beneath a transverse syncline—the east-to-west Staffordshire syncline of Prof. C. Lapworth (Appendix III., No. 2, Part IX., page 6)—and is, moreover, buried beneath an enormous thickness of Mesozoic strata. After this disappearance (to be compared with the disappearance north of Skipton), the chain crops out again in the Charnian range, as pointed out by Dr. A. Strahan (Appendix III., No. 63, page 536), with a north-west to south-east trend. There is little doubt that this is the main axis of the chain, for, before disappearing at Ashbourne, the chain displayed a marked tendency to bend south-south-eastwards. As it is often the case, branch-folds originate round the elbow of the chain and radiate away. In North Staffordshire the southern end of the central division becomes wider, and the deepening and divergence of the Carboniferous Limestone folds give rise to the Potteries, Shaffalong, and Cheadle Coal-Measure synclines. All these synclines and the intervening anticlines pitch beneath the Triassic rocks, and crop out again in the Southern Midland coalfields, often in company with anticlinal faults (boundary-faults). The writer believes that the main axis of the Pennine Chain includes all the pre-Carboniferous outcrops between Hartshill and Charnwood Forest, and that the Leicestershire coalfield is but a minor subordinate syncline wrapped in the main axis, the western margin of which is traced by Hartshill and the eastern margin by Charnwood Forest. The old transverse Charnian range has doubtless undergone many a change before it was rejuvenated by the Pennine upheaval, which adopted its north-westerly to south-easterly trend. The Pennine Chain keeps this trend, at least, up to the latitude of Bedworth; but there, the writer thinks, an important change takes place, and the chain resumes its own north-to-south trend. This conclusion is based on the following grounds:—(1) The trend of the Hartshill, which from Atherstone

* This is the reason why the writer devoted many pages to the study of the other parts of the chain and to the Malvernian range.

to Nuneaton is north-westerly, gradually bends and becomes nearly north to south, where it disappears under the Trias at Bedworth. (2) Further southwards this north-and-south trend is staked out by the north-and-south longer axis of the Permian basin of Coventry-Warwick, by the north-and-south boundary fault of the same basin at Kenilworth, and by the north-and-south western boundary-fault of the coalfield. South of Warwick every noteworthy superficial trace of the chain disappears. If the characteristics of the chain are the same in the southern as in the other divisions, and there is no good reason to believe otherwise, then we may suppose: (1) that the Pennine Chain goes on southwards with this north-and-south trend to meet the Mendip anticline at right-angles, and the meeting might be looked for somewhere between Andover and Farnham. As the Pennine Chain is much enlarged and split where it meets the Dumfriesshire anticline, perhaps in the London Basin, the Pennine Chain might stretch far eastwards of Farnham. The example of the Malvernian range running straight north and south across a country geologically identical, and splitting in front of the Mendips, gives some support to this hypothesis. (2) If the Pennine Chain splits southwards like the Malvernian range, a branch anticline might leave the main axis and run by Ware, Cliffe (on Thames), Bobbington (near Sittingbourne), Chilham, and Brabourne (a line already pointed out by Prof. Boyd Dawkins (Appendix III., No. 22). An intermediate basin in the London area would thus have been included (like the Bristol coalfield)* between the branches of the Pennine Chain, a very speculative supposition indeed. (3) In this hypothesis the Kent coalfield should play, in regard to the Pennine Chain, the same part in the South Wales syncline as the Yorkshire coalfield in the Midland syncline. Then also we might suppose, if the Pennine Chain retains its dissymmetrical structure, that a still deeper coalfield exists west of the chain in the South Wales syncline, just as the deep Lancashire and Cheshire coalfield rests in the Midland syncline.

The writer, however, will deal more fully with this hypothetical coalfield in the sequel.

Many people, no doubt, will believe that the writer is going

* See Fig. 3 for the position of the Bristol coalfield between the branches of the Malvernian range.

rather far in the way of supposition and hypothesis, but it may be stated that there is no danger in hypotheses unless one attributes more importance to them than they are worth. One ought to consider them only as a "fil conducteur" or clue and a way of utilizing the data known up to date. If the geological structure of Southern England is like what the writer supposes it to be, then he may state that there are three anticlinal ridges—the Pennine Chain, the Malvernian range, and the Usk anticline, displaying the same north-and-south trend, the same eastern origin of impulse, and the same dissymetrical profile. Moreover, they show a decreasing importance and extent from east to west. All these characters are classical for a mountain range, and as there is no doubt, according to the best authorities (Teall, Appendix III., No. 69; Strahan, No. 63, page 535) that the upheaval of the Pennine Chain is of Stephanian age, then these three ridges are also coeval. Even regardless of the general influence of the Pennine Chain, it must not be forgotten that there is no hope of finding any coal along its course. The Coal-Measures which might cover the Pennine Chain have been uplifted with the Chain, and swept away by subsequent denudations.

### (4) *The Shropshire Coalfields.*

In the foregoing sections the writer has explained the features exhibited by anticlines. In order to obtain a more complete idea of the Carboniferous belt, we may now consider the structure of some synclines.

From a geological standpoint the coalfields of the Shropshire Borderland are unsurpassed, as they present a most curious entanglement of the various influences intervening in the building-up of the belt. No better example is to be found anywhere, showing the complexity of the history of a coalfield and the numerous changes which it may present, and it needs a thorough and minute knowledge in order to trace this history and its consequences. If, for a moment, it be supposed that these coalfields were still buried, like the south-eastern field, under a thick cover of post-Carboniferous deposits, one will have an idea of the difficulty of the study of a concealed coalfield. Regardless of pre-Carboniferous movements, it is quite certain that the first structure exhibited by the district of the Shropshire coalfields was a series of folds striking north-east to south-west. There is no

data available to decide whether these folds are anterior or posterior to the Viséan period. Some time, however, before the end of this period, the Viséan sea of the Midlands invaded the country along the north-western margin of the Coalbrookdale coalfield. From Lilleshall to the eastern flank of the Wrekin, the Viséan sediments become much thinner and coarser (Prestwich, Appendix III., No. 52, page 426), and, therefore, we have evidence of the nearness of a south-western shore. It has already been explained* that a bay of the South Wales Tournaisian sea stretched north-eastwards in the Titterstone Clee Hills, and probably as far as Baginswood in the Wyre Forest (Arber, Appendix III., No. 7, page 435),† and the north-eastern shore of this bay was not very far away. We do not know the former extent of these successive Lower Carboniferous deposits, but we are quite sure that after the Viséan the Shropshire platform was uplifted and remained so for a long time, during which active denudation took place. This emergence lasted till the Middle Coal-Measure Period, when the district was again invaded by the waters of the Upper Carboniferous basins of the Central Midlands. Taking advantage of the pre-existing folds and synclines, these waters, during the invasion, kept a south-westerly course along the two former Lower Carboniferous synclines. It may be supposed, therefore, that the Middle Coal-Measures of South Staffordshire stretched south-westwards across the Wyre Forest, filled the Highley-Shatterford and Kinlet region of this coalfield, and reached the region of the Clee Hills. Along this course these Middle Measures underwent a lithological change towards the south-west, which was produced by some mysterious causes. In the interval, and also not long before the end of the Middle Coal-Measure period, the northern part of the Coalbrookdale coalfield was invaded by the waters coming from the north-east. The Middle Coal-Measures overstepped very much the Lower Carboniferous rocks of the former synclines. We are at a loss to trace the former extent of these Middle Measures and to settle the question whether they stretched from one syncline to the other over the intervening Bridgnorth anticline. The Middle Measures of both synclines are different in

* See page 105.

† The writer has made use of a great deal of the history of the district from this paper.

many respects, but the interval between them is sufficient to afford room for gradual transitions, inasmuch as the Claverley boring, the site of which is on the intervening anticline, has proved, in some respects, Middle Measures of intermediate character. But unfortunately it is not known whether the Claverley measures belong to the upper or to the lower part of the neighbouring Middle Measures (information on this point would be very useful, in order to trace the history of the Bridgnorth anticline). The existence of the base of the Middle Coal-Measures on the top of Sherlot Hill (Coalbrookdale), at a much higher level than the surrounding Transition Measures, also gives evidence of a former large extension of these measures over the Bridgnorth anticline (Appendix III., No. 52, Plates XXXV. and XXXVI., Figs. 1 and 12). In the Wyre Forest the rapid change of the Middle Measures of the Kinlet region towards Dowles Valley and Shatterford trace out the original margin in this direction, and also indicate that the Abberley Hills and Trimpley anticline were already partly uplifted. After the Middle Coal-Measures were laid down, a new and important movement again folded the district from Denbighshire to Warwickshire. This movement, always along the old Caledonian trend so characteristic of this country, gave rise to the so-called "Symon Fault," and, according to Clarke's description, to a series of folds striking north-east to south-west. Afterwards the uplifted anticlines were planed by denudation, and an even platform stretched along the Shropshire Eastern Borderland. With the advent of the Transition Measures, an important change took place. The general north-and-south trend of the Coalbrookdale, Wyre Forest, and numerous inliers up to the Newent coalfield, gives evidence of a precursory Malvernian folding. The important syncline produced by this folding allowed of the Transition Measures concealing and overlapping on a large scale the pre-existing Middle Measures (unconformity of the Symon Fault). But this Malvernian folding was unable to go beyond the Caradoc-Wrekin ridge, for no traces of it are to be seen in the Shropshire northern borderland (Shrewsbury and Le Botwood coalfields); where the Transition Measures were deposited in the pre-existing north-east to south-west synclines. The edges of the north-eastern to south-eastern folds of the Longmynd and of the Long Mountain are sharply cut along a north-west to south-east

direction by the south-western limit of both these coalfields. This sharp line does not look like the result of a Charnian fold, but more like the result of transversal subsidence along one or more normal faults* (*Graben* subsidence). The main Malvernian upheaval and its effects on the neighbouring coalfields have already been described, and do not need further comment.

Afterwards a local but not unimportant folding left conspicuous traces in the Wyre Forest. This folding, of Charnian trend, gave rise to a series of folds in the Wyre Forest coalfield. From south-west to north-east they are as follows:—(1) The small faulted anticline of Neen Sollers (Silurian rocks); (2) the Mamble coal-basin (Transition Measures); (3) the Heightington anticlinorium (Appendix III., No. 15, page 11, Old Red Sandstone); and (4) the Areley Kings syncline (Transition Measures). The age of this folding is not quite ascertained. The Upper Coal-Measures (Lower Permian) are involved in the folding, and perhaps also the Permian of Church Hill. The Permian rocks of Enville display the same north-westerly to south-easterly trend (Appendix III., No. 47, Plate VIII.), and therefore the folding may be post-Permian. The Shropshire coalfields are much faulted, and the fracture-lines run along one or other of the disturbances previously quoted. They have been carefully mapped by Prestwich, and Dr. A. Strahan has traced the course and the history of the most important of them (Appendix III., No. 63, plate). The writer need not therefore dwell on this subject, as enough has been said, he thinks, to show how complicated the history may be of small tracts of coalfields during a few geological periods.

### (5) *The Kent Coalfield.*

Since the discovery of this coalfield by Prof. Boyd Dawkins (Appendix III., No. 21), good work has been done to prove its characters and particulars, and an important mass of information has been gathered. Even from the palæontological standpoint, this coalfield, through the exertions of Dr. Arber† and Mr. H. Bolton (Appendix III., No. 13), is better known than many older productive fields. Nevertheless, much indeed remains to be done in order to obtain a thorough knowledge of this curious coalfield.

* Such north-west to south-east normal faults are also well shown at the south-western limit of the Coalbrookdale coalfield (Appendix III., No. 52, Plate XXXV.).

† A bibliography of the Kent coalfield may be found in the paper by Dr. Arber (Appendix III., No. 8).

The writer intends to study the problems of this district, which are interesting for the purpose of this paper, under the following headings:—

(1) *Position of the Kent Coalfield in the South Wales-Namur Syncline.*—A glance at a map of the coalfields of this syncline shows at once that there are two distinct forms among them. For instance, the pear-shaped Bristol coalfield is very different from the canoe-shaped Belgian coalfields. All the English and Irish coalfields of this syncline belong more or less to a circular type, while all the Continental fields belong to the elongated type. The difference between both types is not merely one of shape only, but of structure also, the elongation being due to an intense longitudinal folding keeping pace with many disturbances and thrust-faults. Although the limits of the Kent coalfield are still obscure, there is no doubt that it does not exhibit the shape of a narrow east-and-west trough, nor the sharp folds of the Continental type. The horizontality (or nearly so) of the strata in the records of most of the borings and pits, the gentle dip along north-and-south cross-sections, and the slight undulations displayed in the colliery workings, bear no resemblance to the structure of the nearest French coalfields, but remind us of the structure of the South Wales coalfield (north-eastern corner). Therefore the limit between both types must be somewhere in the Straits of Dover.

(2) *Relationship of the Kent Coalfield with the other Coalfields.*—From the abundance of marine beds in its strata, and from the identity of the fauna with the marine fauna of the Middle Coal-Measures of the other coalfields, we know (H. Bolton, Appendix III., No. 13, page 213) that these measures were deposited in a basin having open and important connexions with all the other coalfields of North-Western Europe where such marine beds have been found. On the eastern shore of the Straits of Dover the Middle Measures are wanting, or are much reduced; therefore the connexion with other coalfields was doubtless during this period through the west. There is now a series of borings from Brabourne* to Chilham, Bobbington, and Cliffe, where

* No fossils have been found in the Palæozoic rocks of Brabourne. Through the courtesy of Dr. A. Strahan, the writer had the opportunity of studying these rocks in the Geological Survey collections. Such black shales are very scarce and accidental in the Continental Devonian, but very common in the Silurian and Cambrian. Mr. J. Pringle has pointed out to the writer the resemblance between these shales and the Cambrian rocks of the Calvert boring (Appendix III., No. 19).

Silurian rocks have been proved. From the known north-to-south width of the coalfield, there is little or no hope that it might cross this Silurian barrier, already pointed out by Prof. Boyd Dawkins (Appendix III., No. 22). Therefore the former western extension of the coalfield has been cut by upheaval and denudation. This barrier may be a branch of the Pennine Chain,* or a peculiar transverse ridge. Behind the barrier, westwards, the numerous borings scattered in the London area (Strahan, Appendix III., No. 66, Plate A) all proved pre-Carboniferous rocks, and, in consequence, little hope is left of finding an actual connexion in this direction with the coalfields of South-Western England. A northern margin of Carboniferous Limestone is well proved by the results of borings (Arber, Appendix III., No. 8, Plate XXIV.).

The writer will deal later on with the southern margin. As to the eastern margin, French geologists have taken into account the direction of the Artois axis and the west-north-west trend of the Boulonnais coalfield, and they formerly looked for the westward prolongation of this coalfield in Sussex; and from the same idea, no doubt, the sub-Wealden boring and the Pluckley and Penshurst borings were put down.

The problem is still more intricate since the discovery of the extension of the coalfield as far northwards as Ramsgate. The writer believes it possible to remove the difficulty, for he has made a careful study of all the borings and workings for coal in North-Western France, and he intends to publish a paper on this question. As a summary of the results of this study, the writer may quote the following data:—The north-western extremity of the Pas-de-Calais coalfield is on, or near, the apex of a transverse fold which separates the Continental from the British Coal-Measures. East of this axis the general pitch of the basin is eastwards, while on the west it is westwards. By a series of folds *en échelon* (see Strahan, Appendix III., No. 63, page 537) the Coal-Measures west of this fold make for the north-west up to the outcrops of the Boulonnais. Numerous trial-borings have been put down west of these outcrops in search of the Dover Coal-Measures. From the results of these borings one may infer that the same structure *en échelon* occurs. Two folds roll in, amidst Silurian rocks, Devonian, Carboniferous Limestone, and Coal-

* See page 133.

Measures. The northernmost fold has been proved by the borings of Calais, Marck, and Offekerque, which found Upper Devonian and Lower Carboniferous rocks, sometimes horizontal. This is, the writer thinks, the true prolongation south-eastwards of the Kent coalfield in the older rocks. The axis of the Kent syncline, as drawn by Arber (Appendix III., No. 8, Plate XXIV.), prolonged south-eastwards falls in this Calais syncline. According to the intensity of denudation, the Coal-Measures may, or may not, stretch from the northern syncline to the Coal-Measures of Strouanne in the intermediate syncline, and from this one to the Boulonnais coalfield.

(3) *The Big Overthrust Fault* (*Faille du Midi*).—All along the South Wales-Namur syncline this fault plays an important part in the structure of its southern margin. All along the plane of this and of the associated faults extraordinary disturbances took place, and a most complicated structure originated. To trace the course of this fault in a coalfield of this syncline is, therefore, of paramount importance, as much from the industrial as from the geological standpoint. From the Mendips to the Boulonnais coalfield there is not the slightest clue as to its existence, although every probability points to its continuity, especially in Kent, not far from the Boulonnais, where the overthrust of the faults is more evident than elsewhere, nearly the whole coalfield being still buried under thrust Carboniferous and Devonian formations. We have therefore to rely entirely on theoretical speculations to trace the fault, and the writer will proceed, by way of comparison, from the known to the unknown. If a north-to-south line be drawn from the Forest of Dean to the Mendips, three synclines are found along this line, the structures of which are different. Starting from the big overthrust fault running along the northern slope of the Mendips, the writer finds:—

(1) The Radstock portion of the Bristol coalfield, which is absolutely of Belgian type, as pointed out long ago, with thrust and slide faults, and overfolded and sharply plicated beds. It may be said at once that hitherto there is nothing in the Kent coalfield to remind us of such a structure.

(2) The northern portion of the Bristol coalfield, separated from the foregoing by an overthrust east-and-west anticline, is much more regular, but still disturbed by normal faults, and

displays rather steep dips. In both these synclines the sequence from the Lower Carboniferous up to the Upper Coal-Measures is continuous or nearly so.

(3) Forest-of-Dean Coalfield: Regardless of the Malvernian disturbances on its eastern margin, this syncline is much more regular, and its more perfect basin-like structure is known. The Upper Coal-Measures of this coalfield rest unconformably on the Lower Carboniferous.

By comparing the characters of the Kent coalfield on the one hand with these three synclines on the other, the writer is inclined to believe that the position of the Kent Basin transported on the above line should be midway between the Forest-of-Dean and the Bristol coalfields, where formerly, before denudation, doubtless Middle Coal-Measures rested unconformably on the Lower Carboniferous, as they do in Kent, and where the structure was no less regular. The strata of the Kent Basin seem to have undergone little disturbance, for no trace of faulting has been recorded in the borings, except at Mattice Hill, and yet the borings are in such a number that faults of importance would hardly have escaped detection in one or more boreholes. Even in the southernmost part of the known coalfield area, in the Dover Colliery, the rocks are nearly horizontal, this affording no clue of the approach of the fault. The big fault reaches the French shore of the Straits at Cape Gris-nez, with a west-north-westerly trend (Olry, Appendix III., No. 50, Plate II.). It seems very difficult to trace the fault from Gris-nez to the east of Brabourne, as L. Breton did, for this would need a sharp bend of the fault. If no change takes place in the trend of the fault in the Straits of Dover, the fault must run much further southwards, leaving room, south of Dover, for another coalfield displaying the two kinds of structure of the Bristol coalfield. This hypothetical coalfield may or may not be separated from the Kent coalfield (like the Forest-of-Dean field) by a ridge of older rocks. Against these hypotheses the writer may quote the fact that the Kent coal is reported to be brittle and crumbling like the Belgian coal, doubtless under the influence of disturbances incompatible with the above suppositions.

### (6) *The Concealed Coalfields of Southern England.*

In 1905 Dr. A. Strahan pointed out that, regardless of the Kent area, no fresh light has been thrown on the problem of the

existence of coal in Southern England. The same statement may be made to-day. Some borings, since 1905, proved the Palæozoic floor in the London area, but the problem is still more obscure. In 1902 the writer attempted to sketch the structure of the London area (Appendix III., No. 58), assuming this to be comparable with the structure of the Hercynian folds in Northern France, and supposing the red rocks of the South of London borings to belong to the Lower Old Red Sandstone. The Old Red Sandstone age of these rocks is no more questioned to-day, but since the boring at Southall it seems probable or possible that they are of Upper Old Red Sandstone age. As is well known, the Old Red Sandstone which borders the coalfields of South-Western England bears many resemblances and differences to the Devonian rocks of the Continent, the most striking difference being the existence, on the Continent, of a marine Middle Devonian division. The indubitable existence of marine Middle Devonian in two London borings shows the connexion of the London area with the Continental Devonian. Through the courtesy of Dr. A. Strahan, the writer had the opportunity of studying the red rocks from the Streatham and Crosness borings, and he has had some personal experience of these red rocks, for he mapped an extensive tract of them for the Geological Survey of Belgium. Moreover, in recent years he has split thousands of metres of cores of boreholes through the same rocks (Appendix III., No. 62). From their lithological characters, he had no doubt that the Streatham and Crosness red rocks were Lower Old Red Sandstone, for they are unlike any Upper Old Red Sandstone that he has seen. But afterwards he had the opportunity of studying the red rocks from the Southall boring, through the courtesy of Prof. W. W. Watts and Mr. E. Proctor, in the collections of the Royal College of Science; and also through the courtesy of Dr. A. S. Woodward he saw the same rocks and their fossils in the Natural History Museum, South Kensington. Dr. Woodward, who determined the fishes from this boring (Appendix III., No. 53), pointed out to him that they are beyond any doubt Upper Old Red Sandstone fishes, and still these Southall rocks from their lithological characters are of Lower Old Red Sandstone type. We have therefore no means of settling the problem of the age of the red rocks of the London area on lithological grounds. Moreover, according to the latest map of the London borings

(Appendix III., No. 66), these red rocks surround the two borings where marine Middle Devonian fossils have been found. At any rate, this structure is different from that observed in the immediate neighbourhood of any French or Belgian coalfield.* Therefore, should any coal exist in the London area, it ought to lie much further southwards, a conclusion already arrived at by Prof. Boyd Dawkins (Appendix III., No. 22). The true Lower Old Red Sandstone (Lower Devonian) and the big fault which runs along its northern margin should be, therefore, also much further southwards, a conclusion agreeing with the above study of the Kent coalfield.

As the writer has already stated, there is some probability of the existence of another coalfield west of the main Pennine anticline. Many years ago Prof. Edward Hull put forth an ingenious idea (Appendix III., No. 1, Vol. I., page 155). He had shown (No. 41, page 526) that the Carboniferous rocks owe their basin-shaped structure to the intersections of the two north-to-south and east-to-west systems of post-Carboniferous flexures. Applying this observation to the study of the concealed coalfields of Southern England, he stated that the position of the supposed coalfields, lying between these flexures, may be predicated by the knowledge of the southward prolongation of the transverse anticlines of the Midlands and of the position of their intersection with the main anticline.

Now that the writer has attempted to trace these Midland anticlines southwards, he will deal with the intervening syncline, regarding which he may state the following considerations:—

(1) No transverse anticline is known in the Southern Midlands between the Malverns and Charnwood Forest, except the unimportant Lickey Hills and Dosthill. Therefore one may hope that the southern syncline does not involve important transverse divisions.

(2) As the Woolhope anticline is seen crossing the Malvernian range, it is likely to stretch to the Mendip anticline and to break the south-western corner of the syncline.

(3) There is some possibility of the syncline being cut diagonally by a hypothetical north-east to south-west Caledonian ridge, the north-eastward prolongation of some Cornish

* This structure is similar to the Bristol coalfield, where Old Red Sandstone surrounds a core of younger rocks.

anticline (perhaps the one previously quoted*), and staked out by the underground ridge of Calvert-Bletchley. Actual ridges of the buried Palæozoic platform are not to be mistaken for tectonic ridges, as rightly pointed out by Dr. A. Strahan (Appendix III., No. 66, page lxvii.). But in this case, as he says, the age of the rocks of this ridge is highly significant of an old line of upheaval, inasmuch as the ridge was the south-eastern shore of the Triassic sea of Central England (Davies and Pringle, Appendix III., No. 19, page 340, Plate XXXIV.).

(4) If the dissymmetrical profile of the Pennine Chain holds good at its southern end, then the syncline west of the chain must be deeper than the syncline east of it (the Kent syncline), and in this syncline the deepest part must be at its south-eastern corner, and therefore south of the above diagonal ridge.

(5) There is some actual evidence of the existence of Coal-Measures in this syncline, as the results of the Batsford and Burford borings prove. From the section of these borings there is some reason to believe that Upper Measures were struck, which is in accordance with the fact that these borings are not far from the crest of the Wales-Brabant anticline (Appendix III., No. 19, page 336), and also with the overlap observed along the parallel line of the Malvernian range. The existence of the supposed Upper Measures not far from the southern limit of the Upper Measures of the Midland syncline is another evidence that a large part of the Wales-Brabant anticline was submerged, in England, during the Upper Coal-Measure period. Another tract of these Upper Measures may have extended along the eastern slope of the Pennine Chain (between Kent and Yorkshire); but as this coalfield was shallower, and as this part of England was, during long periods, country of high relief (Strahan, Appendix III., No. 66, page lxxvii.), these measures have doubtless been denudated.

The writer does not intend to describe other coalfields, for a volume would be necessary for such a purpose. Enough has been said, he thinks, to prove the complexity of the problem involved in defining the relationships between the detached coalfields and their extent. The hypothetical character of most of his conclusions will prove, beyond any doubt, how far we are still

* See page 102.

from a perfect settlement of this problem, and how much this settlement is dependent on the more or less advanced state of knowledge regarding all the geological features of these coalfields and of the surrounding country.

The writer cannot conclude without acknowledging the hearty assistance that he has enjoyed in the difficult conditions under which he has written his paper. His gratitude is especially due to Dr. A. Strahan, Director of the Geological Survey, through whom he obtained the necessary books from the London libraries, and to his old friend, Mr. Lewis Abbott, of St. Leonards, who put his rich library at the writer's disposal; to Mr. Butterfield, who allowed him the use of books from the reference library at Hastings; and to Dr. Walcot Gibson, Dr. Newell Arber, and Mr. H. Bolton, who supplied him with maps and books of their own.

## APPENDIX I.

In the magnificent work of Edward Suess, in which he expounded his brilliant synthesis of the mountain ranges, there are, doubtless, some points which require revision. As is often the case, Nature is not so simple and systematic as one is at first inclined to believe. The writer is quite sure that the Caledonian ridges of the British Isles display the entanglement of two foldings of different age, the first (the oldest) with a north-north-easterly trend and a direction of impulse from the east-south-east; the other with a north-easterly trend and a direction of impulse from the north-west. Suess was well aware of these phenomena, which he attributed to fan-structure. It is beyond the scope of this paper to unravel this entanglement, inasmuch as both foldings are pre-Carboniferous. The writer will be content to make some remarks on subjects related to mountain building which have a direct connexion with the purpose of the present paper.

*Age of a Mountain Range.*—Suess seems to have been of opinion that mountain-range formation does not extend over more than one definite period. He was perfectly aware of the movements still displayed by a fold after it reached its climax, and to these movements he gave the name of "posthumous movements." But he never mentioned the folds which long before them prepared the main upheaval and which the writer has called, in this paper, "precursory movements." For example, Suess states at times that the Armorican range was initiated in late Carboniferous times, and, again, that it reached its climax at that same period. The writer has already shown, for Belgium, that the principal features of the Hercynian range existed long before the Stephanian Period (Appendix III., No. 59); also, in the present paper, it has been shown that in North-Western Europe many big folds displayed repeated signs of oscillation, uprise, subsidence, and again elevation, before the main folding occurred. Here are the following evidences of a very early activity of Hercynian folding:—(1) The

differences between the sediments and fauna of the Devonian System in Devon and Cornwall and those of the same system northwards is so well known that it needs no argument. The difference is such as to give clear evidence of a pre-Devonian ridge between the two distinct types of rocks and fauna. The ridge does not coincide with the actual main anticline (Mendips), but runs along the North Devon coast to Bridgewater in an east-south-easterly direction parallel to the Hercynian trend in this district. This ridge continues eastward, buried beneath more recent formations, reappears along the axis of Artois, and is well known in Belgium, where it runs along the northern margin of the Dinant syncline at least up to Aix-la-Chapelle, and the difference on both sides of the ridge is still more important than in England. All along this course the pre-Devonian ridge is parallel to the Hercynian trend, and, so far as the writer is aware, it is the earliest symptom of Hercynian activity. (2) When the Caledonian folds of Wales, in their south-westerly course, approach the Hercynian folds of the South Wales coalfield, they display a remarkable bending already described by De la Beche (Appendix III., No. 20, page 24) and by Suess (No. 68, page 129). They turn round gradually until, north of Carmarthen Bay, they strike nearly east and west, like the Hercynian folds. The change in trend is clearly shown in the recent maps published by Prof. O. T. Jones (Appendix III., No. 42, Plate XXXII.). Doubtless some part of this change was produced by the pressure from the south of the Hercynian folding. A map accompanying the paper published by O. T. Jones and H. H. Thomas (Appendix III., No. 43, Plate XL.) displays the extraordinary disturbances of the pre-Carboniferous rocks of Pembrokeshire, and shows how the faulted masses adapted themselves to the new conditions. The authors attribute a post-Carboniferous age to some of the faults of the district; nevertheless, there is evidence that a good deal of the change in trend is due to an early tendency to Hercynian folding. This evidence is furnished by the continuous overlapping of the southern margin of the Siluro-Cambrian *massif* of Wales by more and more recent formations towards the west. This overlap commenced in the Lower Old Red Sandstone and continued on, at least, to the Middle Coal-Measures along St. Bride's Bay. The overlap, which kept pace with the change of trend, was doubtless coeval with the faulting northwards, which itself is an early symptom of Hercynian activity.

Suess was of opinion that the main or internal Armorican ridge was of late Carboniferous age like the external one. But all the folds of a mountain range are not necessarily of the same age, as the age of a ridge is not a distinctive characteristic for tracing its relationship. The trend and still more the direction of impulse are much more important. From the relations of this internal ridge with the Saarbrück coalfield, where a continuous and not much disturbed sequence from the Middle Coal-Measures right up to the Permian is to be found, it may be presumed that this ridge was uplifted before the Stephanian Period. As the direction of impulse in the Armorican range is from the south, it is not at all surprising that the southernmost ridge was first uplifted. As the term "Armorican" was intended by Suess to designate the western part only of the range, the writer prefers to use, like Marcel Bertrand, the term "Hercynian" for the whole range.

*Transverse Folding.*—The part played by this kind of folding in the tectonics of disturbed districts was omitted by Suess, who sometimes quoted

with amazement the existence of folds at right-angles with neighbouring ridges. Doubtless this kind of fold is much less important and more difficult to detect than longitudinal folds (folds parallel to the longer axis of the range), but they are by no means unimportant. Transverse folds are especially conspicuous, and they may play the part of a true mountain range in some districts, as, for example, in Central England, where longitudinal folds are gentle and broad. In districts where intense and sharp

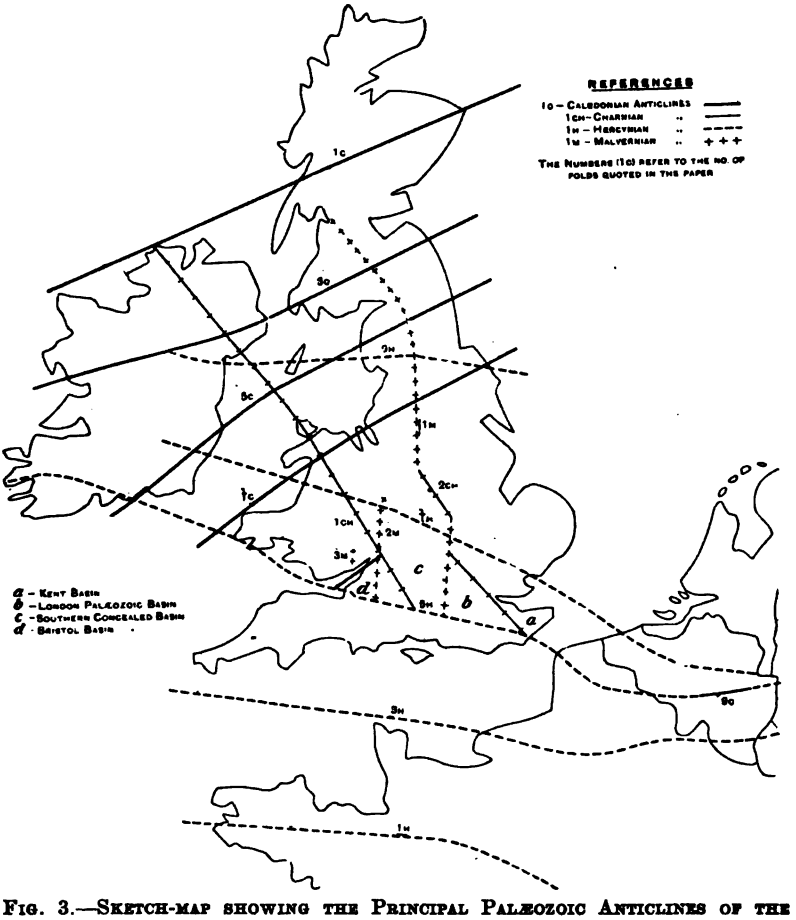
REFERENCES
1c – Caledonian Anticlines
1ch – Charnian
1h – Hercynian
1m – Malvernian
The Numbers (1c) refer to the no. of folds quoted in the paper
a – Kent Basin
b – London Palæozoic Basin
c – Southern Concealed Basin
d – Bristol Basin

Fig. 3.—Sketch-map showing the Principal Palæozoic Anticlines of the British Isles.

folding took place, as in Belgium and in Scotland, they are short, irregular, and unimportant. The axes of these folds, in their courses across the pre-existing longitudinal folds, run along the shorter axes sometimes of synclines and anticlines. The case is the same for the axes of longitudinal folds, but the passage from anticline to syncline is much less frequent, as these axes run along the longer axes of these folds. By the intersection of longitudinal and transverse folds, a country which has gone through the formation of two

mountain ranges of different trend is covered by a complicated net of folds, and owing to them this part of the earth's crust has become a "shield." Such a plaited shield, according to the laws of mechanics, is very strong; it therefore resisted further folding, and was more liable to break than to fold again. The sketch-map (Fig. 3), in which the principal anticline axes of the British shield are represented, explains why this shield was never liable to yield to enormous subsidences like those which are known to exist in Holland and in Northern Germany.

## APPENDIX II.

The numerous dales which intersect the outcrops of the northern and eastern margin of the Lancashire coalfield afford an unequalled opportunity of studying the strata between the Middle Coal-Measures and the Carboniferous Limestone. The classification of these deposits, made as the result of the observations* of two generations of geologists, has become classical, and was adopted by Prof. Hull in his classification of the Carboniferous deposits of the British Isles (Appendix III., No. 39). Among the divisions drawn in these Carboniferous rocks is the Lower Coal-Measure division. The writer will, first, summarize the most persistent particulars exhibited by these Lower Coal-Measures of Lancashire. They present, in ascending order, the following sequence:—

(1) *Barren Measures.*—These contain grits and occasional coals, and some marine beds.

(2) *Productive Measures.*—These contain one to three thin but persistent coals, often displaying "gannister seats." The middle seam has sometimes a freshwater or brackish fauna (*Carbonicola*) in the roof. The two other seams display marine faunas in their black-shale roof, especially the uppermost coal (Bullion), whose roof of shale with limestone nodules (Bullions) is crowded with marine shells (*Pterineopecten* and *Goniatites* being especially conspicuous).

(3) *Barren Measures.*—These contain impersistent, thin, and unworkable coals, and near the top a persistent series of flagstones or grits.

(4) *Middle Coal-Measures.*—These contain the Arley Coal at the bottom. This regular coal-seam is noteworthy for its roof, which contains abundant fish-remains. Prof. Hull was of opinion that the Lower Coal-Measures are the upper limit of marine Carboniferous faunas. The inaccuracy of this statement is known, and the utility and limits of the Lower Coal-Measure division have been questioned. The writer thinks that there are good reasons for retaining the limits of this division as drawn by the Lancashire geologists. The same sequence and particulars hold good in the contemporaneous beds on the eastern wing of the Pennine Chain in Yorkshire and Derbyshire. From the description of the Cheadle coalfield by G. Barrow (Appendix III., No. 10), it seems to the writer that, owing to favourable outcrops, one may observe there quite the same particulars in the Lower Coal-Measures, and the same faunas. The writer long ago had the opportunity of studying with his friend, the late Mark Stirrup, some typical sections of the Lancashire Lower Coal-Measures. In these sections he was able to identify the minute par-

* The writer may add that a good deal of these observations have been published in the *Transactions of the Manchester Geological and Mining Society.*

ticulars that he had observed in Belgium. Taking into account the distance between Lancashire and Belgium, and the fact that the coalfields of both countries do not belong even to the same syncline, the identity of their lithological, faunal, and stratigraphical characters is really wonderful and one of the strongest evidences of the former extensive connexions between the British and Continental Coal-Measure areas. The writer has been able to follow the Lower Coal-Measures all around the Belgian coalfield, over hundreds of miles, and they always display the same characters. They have been found by W. C. Klein in the Dutch Limburg and in the Wurm coalfields, and they are known to exist in Westphalia. A coal-seam presenting all the characters of the Arley Seam of Lancashire occurs at the bottom of the Middle Coal-Measures (Appendix III., No. 60) in the Belgian, Dutch, and Wurm coalfields. In the North of France C. Barrois has already detected, notwithstanding the lack of outcrops, the fossiliferous level of the famous Bullion coal. In the British Isles the Lower Coal-Measure rocks and fossils are still unknown in some coalfields, but for some of them this is only due to lack of observations. A fair example of this is afforded by the Bristol coalfield, which was formerly noteworthy for its scarcity of faunal horizons (especially of marine horizons). No sooner was Mr. H. Bolton able to undertake the study of this coalfield than he detected many fossiliferous levels of every kind. From the two papers (Appendix III., Nos. 11 and 12) he has already published on the question, it is easy to grasp that typical Lower Coal-Measures have been found in the Bristol coalfield resting on Millstone Grit and displaying the same sequence and faunas as in Lancashire. From the descriptions of the South Wales coalfield published since the re-survey of this country, and from the fossils formerly described by J. W. Salter (Appendix III., No. 54), the writer has little doubt that the Lower Coal-Measures are also present in this coalfield (No. 67). In conclusion, the writer may state that a division which displays such a persistency of characters over so extensive an area is worthy of retention. As to the utility of these rocks being separated from the others, it may be said that the Lower Coal-Measures by their bareness are the true Farewell rocks in deep mining. If the Lower Coal-Measures are not, as Prof. Hull thought, the upper limit of marine faunas in the Carboniferous, nevertheless marine beds are the rule in this division, and freshwater beds the exception, whereas in the Middle Coal-Measures the contrary is the case. A noteworthy difference between both divisions is the scarcity of plant-remains in the Lower Coal-Measures, a fact which is correlative of the abundance of marine bands. As previously mentioned, the Middle Coal-Measures are really the period of coal-formation, and by their faunal and lithological characters the Lower Coal-Measures are more closely allied to the Millstone Grit than to the Middle Coal-Measures.

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The President (Mr. Leonard R. Fletcher), in moving a vote of thanks to Prof. Stainier for presenting so valuable a contribution, suggested that the discussion should be postponed until the paper had appeared in the *Transactions*.

The resolution was carried.

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## THE MINING INSTITUTE OF SCOTLAND.

GENERAL MEETING,
HELD AT THE HERIOT-WATT COLLEGE, EDINBURGH, FEBRUARY 12TH, 1916.

Mr. DAVID M. MOWAT, PRESIDENT, IN THE CHAIR.

The minutes of the last general meeting were read and confirmed.

Office-bearers for the session 1916-1917 were nominated; and Messrs. Thomas Brown and John Barrowman were appointed to audit the Treasurer's accounts for the year.

## DISCUSSION OF MR. MARCEL GILLIEAUX'S PAPER ON "LINING SHAFTS WITH CONCRETE Z-BLOCKS."*

Mr. MARCEL GILLIEAUX (London) wrote that, in the first place, he was glad to express his thanks to the members of the Institute for the cordial reception of his paper and the discussion thereon by the members.

The President (Mr. Mowat) had set forth admirably the author's claims in connexion with the new method of lining. There was, of course, no objection to build the Z-block lining upwards like brickwork, and he (Mr. Gillieaux) thought that this method might offer some advantages, chiefly in making good joints between the strata of blocks; but, as Mr. Mowat had stated, the chief object of the system was to permit of the working being conducted downwards, the lining following the sinking step by step, and, besides other advantages, to ensure that the sinking would be completed without temporary supports being put in.

* *Trans. Inst. M. E.*, 1915, vol. l., pages 51 and 431.

With regard to the photographs accompanying the paper, and the question whether the process of lining shafts described had actually been employed, he (Mr. Gillieaux), in order to minimize his expenses, had, with the permission of the General Manager of the Charbonnages de Masses-Diarbois, made his first trial of a length of little more than 3 yards at the bottom of a pit. The photographs illustrating the paper were taken during the provisional setting-up of the first rings above ground. The trial in question was instituted to show the possibility of carrying out satisfactorily in practice the process of building lining downwards with Z-blocks, and this work was effected without special difficulty. Owing to the outbreak of war, he was unable to undertake further work on a larger scale.

The prices given in his paper for blocks measuring 2 feet 3¾ inches long, 2½ feet high, and 7½ inches thick were those paid in Belgium in times of peace. Doubtless these prices were subject to great variation, according to place and circumstances, and he admitted that these costs would now be much higher in Scotland during the war; but, in the case of Belgium, he thought that it was quite possible, if a large number were ordered, to make these blocks even cheaper than 4s. (5 francs) each. He gave below particulars showing how he had calculated the cost, and this would be a guide for other countries:—

Each block contained the following materials:—

| | Francs. |
|---|---|
| 32½ kilogrammes (71¾ pounds) of cement, at 32 francs (25s. 7d.) per 1,000 kilogrammes .. ... ... ... ... ... | 1·04 |
| 220 kilogrammes (4 cwt. 38 pounds) gravel and quarry-dust, at 4 francs (3s. 2d.) per 1,000 kilogrammes ... ... ... ... | 0·88 |
| 9·37 kilogrammes (20 pounds 10 ounces) of iron-bars, second quality, at 130 francs (£5 4s.) per 1,000 kilogrammes ... | 1·22 |
| Total cost per block for materials (2s. 6½d.) ... ... | Fr.3·14 |

His (Mr. Gillieaux's) experience showed that a skilled man with one helper (paid respectively 6 and 4 francs a day) could prepare, finish, and store nine or ten blocks each day. Each block cost between 1 franc and 1·11 francs (10d. to 11d.) to make, in addition to the cost of material. For greater quantities a skilled man might direct more cheaply paid workmen, and the price per block would therefore be less.

The redemption for the mould would not be more than 1d. or

2d. per block, as the same mould could be used for hundreds of blocks. Including inspections, sundries, etc., at 10 per cent. of the general cost, this would amount to 45 centimes (4½d.) The total cost might therefore be summarized as under:—

| | Francs. | s. | d |
|---|---|---|---|
| Material ... ... ... ... ... | 3·14 | 2 | 6¼ |
| Labour ... ... ... ... ... | 1·11 | 0 | 10½ |
| Redemption of mould ... ... ... | 0·20 | 0 | 2 |
| Inspection, sundries, etc. ... ... ... | 0·45 | 0 | 4½ |
| Totals ... ... ... ... ... | Fr.4·90 | 3 | 11¼ |

It was most difficult, of course, to determine in the same manner, after so short an experience, the cost for the setting-up of the blocks and the filling-in behind: both of these items were dependent on too many circumstances. But the estimate of 6d. for setting the block was based on the time and on the number of workmen required for this work. The cost of filling-in depended chiefly on the nature of the strata and on the space between the block-wall and the sides of the shaft, and might differ in each case.

Mr. J. B. Thomson had doubted whether a concrete lining 8 inches thick would be able to keep back any considerable pressure of water. He (Mr. Gillieaux) quite agreed that this thickness was insufficient to resist a strong pressure; but it must be remembered that the thickness of the concrete wall included the filling space, which was always at least 2 or 3 inches thick, and might be as large as desired, and that the filling-in cement binded with the blocks. The thickness of 7½ inches mentioned in the paper was given only as an example, in order to show the different proportions of the materials, whereas the blocks might be made as thick as the circumstances required.

With regard to the wall-pockets for buntons, etc., the cutting of these with picks and chisels would indeed be an expensive matter, but he did not think that it would be a difficult job to make these pockets in the blocks before setting them in position, and in this way to obtain an approximate idea as to their position. The holes might be made much larger than the bunton's ends, and big enough to correct the small differences in the measure. They might even, if necessary, be enlarged by cutting off a small bit at the top or the bottom of the wall-pockets, and this would not be a difficult nor an expensive operation.

With regard to the suggestion to lay a grid of cross-bars on

the bars to support a number of stones where the cavity behind the blocks was too large, he had suggested this only to economize the amount of cement-grouting used. He did not think that this was impracticable, although it depended more on sleight of hand, a matter difficult to explain in writing.

In conclusion, he thanked the members of the Institute for the opportunity that had been afforded him to explain the points raised in the discussion, and would be glad to afford them any further information required on the subject of his paper.

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## DISCUSSION OF MR. SAM MAVOR'S PAPER ON "COMPRESSED AIR FOR COAL-CUTTERS."*

The PRESIDENT (Mr. David M. Mowat) said that the paper was a little belated, seeing that the use of compressed air was practically excluded from Scottish mines at the present time. There were, however, many points concerning its use and defects which could be applied to almost every detail of colliery work.

Mr. Mavor had stated that the development in the use of electricity had not resulted in a general reduction of the amount of compressed air used, and had asserted that—

> "It is important to note that formerly compressed air was used mainly in a comparatively small number of motors of considerable size near the pit-bottom, whereas modern conditions require transmission of air-power long distances in-bye, and its distribution to a large number of motors individually of comparatively small size."

His (Mr. Mowat's) experience was that compressed air was almost solely used to drive coal-cutting machines and pumps in-bye, and not to any large extent out-bye, and he thought that this was the general practice in Scotland.

Mr. Mavor's remarks on the great losses consequent on the use of very small pipes might well be applied to other branches of colliery work and practice. There was no more prolific source of trouble at collieries than the installation of plant that became too small for the work it was ultimately called upon to perform, as, for instance, cables that were too small for their work, or pipes that were too small for the pumps. The members were familiar with instances of the kind, because they were of almost

* *Trans. Inst. M. E.*, 1915, vol. l., page 625; discussion, vol. l., pages 92, 433, 468, and 704.

daily occurrence. If colliery officials only realized what the cost amounted to each year, their eyes would be opened in many cases.

Mr. Mavor had referred to the very low actual efficiency of the compressed-air system in in-bye service, and he (Mr. Mowat) wondered whether the surprisingly low efficiency of between 5 and 10 per cent. mentioned by Mr. Mavor was not the reason for the paper being written by an electrician. This thought had passed through his mind when he studied Fig. 14, because the comparison of the recorded results of cutting by compressed air and by electric machines was really startling. The same observation might apply to the example quoted by Mr. Mavor in which the compressor, although driven by a motor of 120 horsepower, had difficulty in driving one cutter alone, whereas the electric machine, which had replaced a compressor, took only about a twentieth of the power required by the compressor. These were perhaps extraordinary instances of the relative difference between the two powers; but he could confirm this from his own experience. The manager of a neighbouring colliery, with a very considerable experience of the compressed-air system, thought that the single engine installed at his colliery, with a cylinder 16 inches in diameter by 2 feet stroke, would not drive a coal-cutting machine. He (Mr. Mowat) thought that it would, and results proved that his view was correct, because, before the engine was replaced or augmented, three coal-cutting machines were being driven by it. Mr. Mavor had coined a new word as applicable to compressed air, when referring to its "docility." "Docility" was a particularly good and apt word, because there was not the slightest doubt that the docility of compressed air constituted one of its greatest defects. Compressed air never "spoke back," but did what it could just as well as it could. Very often, if trouble developed, it was not the fault of the compressed air, but the fault of the individual who was responsible for having it there. Was there not a hint here of which might be taken advantage in other details of mining, namely, to see that they did not ill-use the medium employed to do their work, no matter how docile it proved itself to be? There was a danger that the medium might be too docile. Mr. Mavor had referred to longwall coal-cutters of the three well-known types; but he did not specify what these types were, whether they

referred to the names of makers or to the disc, chain, and bar class of machine. In dealing with the power required for cutting certain kinds of holing, Mr. Mavor had stated that the energy expended by a coal-cutter motor in very easy coal-cutting was 0·20 brake-horsepower per hour, equal to 12 brake-horsepower running continuously, and so on for other kinds of holing. He had then quoted figures based on the assumption that the machine developed 0·5 brake-horsepower per square yard cut. He (Mr. Mowat) had gone into the matter in connexion with some cutting in which he was interested at the present moment, and found that, in a fair holing of fireclay, the equivalent used by the electrical machine came out at about 0·41 brake-horsepower, which confirmed Mr. Mavor's figure.

One or two points of interest arose out of the discussion on the paper. At a meeting of one of the Federated Institutes,* Mr. Walter Hargreaves had referred to his experiences with compressed air, and stated that he had what he considered a first-class installation of compressed air. He had slow-running compressors and large pipes, but found that, while the ordinary running speed under load was twenty-eight strokes of the compressor, it took eleven strokes to keep up the pressure when no work was being done. This instance showed clearly that there was a considerable leakage somewhere. Mr. W. H. Chambers had also stated that he had recently put in a compressor with electrically-welded tubes. He (Mr. Mowat) had not previously heard of underground tubes being welded in that way, and it would be interesting to learn whether any member of the Institute had had experience of such welding. Electrically-welded tubes might be advantageous in some respects, and not in others. For instance, if the pipe was to be permanent, or not likely to be moved again, the idea might be sound.

Mr. Sam Mavor (Glasgow) said that he was much gratified at the reception of his paper; for he must confess that he had had some qualms as to how it might be received.

Mr. Mowat wondered whether his motive in writing the paper might not, to some extent, have been influenced by his (the speaker's) interest in electrical work. He might say, however, that he was equally interested in the engineering problems of

* *Trans. Inst. M. E.*, 1915, vol. l., page 92.

compressed-air work. The paper was the outcome of the fact that his work had taken him so much into the remoter regions of the mine where, if there were defects in the power system, the consequences were most serious. In the course of his work he had accumulated a great deal of experience and of data, the communication of which, he believed, would be helpful to many members of the Institution. It was true that the paper had not a wide application in Scotland, where compressed air was only used to a limited extent, not only in-bye but near the shaft-bottom for pumping and haulage. The three well-known types of machines to which he had referred were the chain, disc, and bar types. He had avoided particularizing, because he did not wish the discussion to follow the lines of the relative merits of individual types of coal-cutters. The use of welded pipes by Mr. W. H. Chambers of Cadeby was extremely interesting, and he was quite sure that the experiment would be watched with great interest.

In the previous discussion,* Mr. Frank Anslow seemed to have overlooked the fact that the efficiencies of 30 and 40 per cent. mentioned in the paper did not refer to the system as a whole, but to tests on individual motors working at full load and under favourable conditions. These efficiencies expressed the ratio between the energy developed by the motor and that in the air supplied to the motor, disregarding losses in the transmission of the air. Assuming that a compressed-air plant was in fairly good condition, the overall efficiency as defined in the paper, during an 8-hour shift or a 24-hour day, was very largely governed by the load-factor of the plant, and was peculiarly sensitive to the load-factor. An overall efficiency of 20 per cent. during a shift would be very good. It was certainly seldom, if ever, attained in colliery practice, and would be difficult to attain with the fluctuating load of a coal-cutting plant. Mr. Anslow's remarks on measurement were interesting, and his reference to the avoidance of surging of the air through a meter was useful, but the air-meter was not alone among meters in being affected by violently fluctuating flow. The accuracy of nearly every kind of meter, including electric meters, was impaired by a surging current. For this reason an air-meter in a main pipe should be in-

* *Trans. Inst. M. E.*, 1915, vol. l., page 433.

serted at the down-stream end of the receiver, in order to isolate it from the pulsations caused by reciprocating compressors; and meters underground should, where practicable, be inserted at the up-stream ends of the receivers, where the effect on the air-current of delivery to reciprocating motors, or of sudden fluctuation of the demand for air, was cushioned by the capacity of the receiver.

Mr. Thomas Bryson's question as to the effect upon a pressure-gauge of the position of the orifice and its connecting tube relatively to the direction of flow of air in the air-pipe had been anticipated in the course of the enquiry. Experiments were made with the orifice facing up-stream, facing down-stream, and at right-angles to the direction of the stream, and no difference could be detected on the dial of an ordinary pressure-gauge. An instrument of greater delicacy, such as a U-tube, was required to measure the difference of pressure due to velocity-head at the rates of flow usual in air-pipes.

The observation in the paper, that the loss of pressure varied as the square of the velocity, was based on many tests, of which those illustrated in Figs. 7 and 8 were examples. Mr. Bryson had deduced certain values of the exponent of $V$ from the curves on Fig. 7; but different values might be deduced by selecting points at different parts of the same curves. Taking the figures given by Mr. Bryson, it was difficult to see how he could contend that values of the exponent varying from 1·7 to 2·55 supported the contention that the drop of pressure varied as the square of the velocity. The next statement made the argument still more difficult to follow: Mr. Bryson set out to show that the given curves justified the square of the velocity law, and inconsistently concluded by stating that the considerable observed differences from this law were a measure of the accuracy of the experiments. The view expressed in the paper, that the rule was not properly applicable to the larger pipes used in collieries, was consistent with practical experience, as the observed losses of pressure in the larger pipes were much less than the rule would indicate.

An example had recently come under his notice, in which the pressure loss in 1,900 yards of piping, partly of 10 and partly of 9 inches diameter, conveying about 4,000 cubic feet of free air per minute, was almost exactly balanced by the gain of pressure due to the aerostatic head in the shaft-column; but, according

to the theoretical formulæ, the pressure loss should have been about twice as much.

There was no experimental authority for the application of the square-of-velocity rule to such main air-pipes as were usual in collieries. It was originally applied to the flow of water in pipes, and the assumption that it was applicable to pipes of widely different sizes, conveying air at considerable range of pressure and at considerable differences of velocity in the same pipe, was challenged. The problem was much more complex than in the case of water. For example, allowance ought to be made for change of velocity due to expansion of the air as the pressure fell along the pipe; some of the formulæ, such as Rix Johnson's, recognized this. The wide divergence of the theoretical formulæ as illustrated by Fig. 7 was surely sufficient evidence of the unsatisfactory position, and of the need for establishing a formula upon a sufficiently broad experimental basis. Coefficients of air-friction applicable to the surfaces of cast-iron and of mild-steel piping also awaited determination.

Mr. Walter Dixon had referred to the too common view that the compressed-air system in its application was so simple that everyone understood it. This view lay at the root of the inefficiency of the compressed-air system. Compressed air more than any other system of power required close and unremitting attention to its details as a condition of even a moderate degree of efficiency.

Mr. James Black's description of his experience with a small compressed-air pumping plant, with an electric motor driving the compressor, was a forceful illustration of the value of measurement. In this case the measure of the power used was presented by the bill for the electric supply in convincing form, and the penalty of the wasteful method was thus thrust home. Where the cost of power and the efficiency of the compressor were known, an air-meter might be calibrated to record the cash value of the compressed air delivered. The records of a meter which piled up the shillings, like the meter of a taxi-cab, would probably be treated with more deference than those of one that gave a mere summation of cubic feet of air.

Mr. R. W. Dron's complaint that a satisfactory electric rock-drill had not been produced was perfectly valid, but it was not

relevant to the subject of the paper. Hitherto the compressed-air rock-drill, despite its low power efficiency, yielded in practice the highest commercial efficiency, and it had, therefore, held the field against all competitors, including drills on the internal-combustion principle. He (Mr. Mavor) believed, however, that the days of the compressed-air rock-drill were numbered. He had seen in operation a rock-drill, constructed in accordance with an entirely novel system of power transmission, which used only a fifth of the power required by a compressed-air drill, and could be used in association with any existing electrical plant. This system had features which differentiated it from all other attempts to compete with the compressed-air drill, and he believed that it was destined to revolutionize, not only rock-drilling in coal and metalliferous mining, but in all branches of civil engineering and quarrying that were based upon rock-drilling. He was not permitted at this moment to refer more particularly to the new system, but in the near future important developments in this direction would be noted.

Referring to Table VIII. in his paper, it was clearly stated that the labour cost of 4d. per ton was based on a labour cost of 33s. per shift for the coal-cutter crew, and he considered that under normal conditions this was an ample allowance. It was agreed that the items (*a*), (*b*), and (*c*) were not dissimilar for compressed-air and electric machines. Opportunity for a comparison of the relative fuel-consumptions of compressed-air and electric coal-cutting plants was provided at two adjacent collieries in Lanarkshire, where the same seams were worked, where the boilers and steam-engines were of similar type and size, and where the number of machines and the other conditions were similar. For a corresponding output the compressed-air plant used four times the amount of fuel required by the electric plant. Such a comparison was a rough one, but the results in the case referred to were consistent with observations made elsewhere.

Mr. Dron's criticism of the figure 2·76d. per ton for compressed-air power was completely vitiated by his mistake in basing his argument upon the net air-consumption, per square yard cut, measured at the machine, instead of referring to Tables III. and V., from which the volume of air delivered by the compressor. per square yard cut by the machines, could be ascer-

tained. He thus neglected to allow for all the losses of pressure and of volume in transmission, and fell into the common error of ignoring the importance of the "load-factor," which was specially discussed in the paper.

The cause to which explosions in air-receivers were usually attributed was, as Mr. Dron knew, the use of oil with too low a flash-point. The exposure of receivers to the direct heat of the sun, especially in tropical or sub-tropical countries, might be a contributory factor. Explosions had, however, occurred within compressors in cases where the flash-point of the oil was at a temperature higher than that normally due to compression of the air. Derangement of the water-cooling system might permit abnormal rise of temperature in compressor cylinders; in the course of his (Mr. Mavor's) enquiry the interior walls of the water-jackets of some compressors were found to be covered with a thick layer of water-deposited scale, which was a non-conductor of heat. It was possible that local superheating of the air might be caused by friction due to the air being forced through valve areas or ports originally too small, or constricted by deposits of burnt oil or other foreign matter. A considerable amount of energy might be expended in forcing the air through constricted passages, and this energy was converted partly into velocity of the air and partly into heat. There could be no doubt that safety was to be found in the use of an oil with a flash-point so much above the normal temperature due to compression that ample margin was provided.

It was true, as Mr. Forgie had stated, that the cost of maintaining compressed-air plant was less than the cost of maintaining electric plant, but that statement applied to existing conditions whereby electric plant received a degree of attention to its maintenance which was denied to compressed air. Too little was expended on maintaining compressed-air plant, and this was one explanation of its extremely low efficiency. Increased outlay in improving and maintaining the condition of air-plant would, by raising efficiency, be very profitable expenditure.

He was in complete agreement with Mr. Forgie with respect to the losses due to wire-drawing.

As Prof. Daniel Burns had stated, there were misconceptions as to the effects of "wire-drawing" compressed air, but his (Prof. Burns's) own remarks did not tend to dispel them; the

statement that wire-drawing did not seriously affect the efficiency of compressed-air could not be accepted. It was true that, when wire-drawn, the compressed volume of air expanded; but this was only another way of saying that its pressure was reduced in the same ratio. Difficult problems of entropy awaited investigation, but these need not concern them; the practical result of wire-drawing compressed air could be stated so briefly and clearly as to leave no room for misunderstanding. When energy was expended in compressing, for example, 1,000 cubic feet of free air to 60 pounds per square inch, and the air was then so wire-drawn that its pressure was reduced by 20 pounds, there remained 1,000 cubic feet of free air compressed to 40 pounds. The energy that was expended in raising the pressure from 40 to 60 pounds was lost absolutely, without any compensating advantage whatsoever in respect of the efficiency. That statement was sufficiently concise and clear to remove any misunderstanding of the seriously wasteful results of wire-drawing or throttling compressed air. But the loss due to wire-drawing did not end there. In practice, the most mischievous wire-drawing occurred in the smaller valves and piping close to the coal-face, after the pressure of the air had already been lowered by transmission from the surface. Wire-drawing through small valves and hose-pipes at the face frequently so much reduced, not only the pressure, but also the temperature of the air, that the remaining energy had lost much in availability for useful work. The coal-cutter air-motor might run at full speed, but with insufficient air-pressure to develop the required power; the cutting speed was thus reduced, and the volume of air used per square yard cut was extravagantly increased. A practical difference between wire-drawing air through a restricting orifice and wire-drawing it through considerable lengths of piping was that, in the former case, there was a sudden lowering of temperature where the air issued from the orifice, and this fall of temperature involved loss of capacity for useful work; whereas, in the latter case, the air, although equally reduced in pressure at the end of the pipe-line, might have time in its passage to recover the temperature of the mine, so that the loss of available energy would only be that due to the reduced pressure.

Plans of the ventilating system and of the electric power

system were now kept at every colliery; why not also of the compressed-air system? The existence and maintenance of plans showing the routes and sizes of the air-piping, and the positions of valves, receivers, etc., of the air-using motors, would not only provide the manager with a graphic view of the system, and enable him to keep a check upon it, but would also have a wholesome influence upon the under officials whose departures from approved practice would be revealed upon the plans. Up-to-date plans would be a perpetual symbol of the importance attached to method in the maintenance and extension of the compressed-air piping, etc.

The discussion of the paper was closed, and a hearty vote of thanks was awarded to Mr. Mavor.

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## DISCUSSION OF MR. JAMES BLACK'S PAPER ON "FORMING A SHAFT-PILLAR IN THIN SEAMS."*

Mr. R. W. DRON (Glasgow) wrote that he had recently formed shaft-pillars on the system described by Mr. Black, with results that fully justified the innovation. In laying out the pillars, his method was first to lay down a pillar of sufficient size to provide for the protection of colliery buildings. In the case of normal Coal-Measure strata lying at a moderate inclination, he took fully a third of the depth, and marked off that distance around the outside line of the buildings to be protected. The workings within this area were then regulated, so as to allow of the extraction of about 20 per cent. of the coal; and the shape of the pillar was altered, where necessary, so as to leave in rectangular blocks of coal. The roofs and pavements with which he had dealt were composed of fairly strong sandstone, and at a depth of over 1,200 feet there had been no trouble through crush or creep. He had not had similar experience with soft roofs and pavements or with a soft coal, but was inclined to think that in such circumstances there would be less trouble with the longwall places than there would be with places 9 or 10 feet wide. It would be very interesting if some of the members who had experienced difficulties in maintaining roads through the shaft-pillars could give their views on this point.

* *Trans. Inst. M. E.*, 1915, vol. l., page 449.

Mr. Black had shown in Fig. 1 of his paper a very small solid pillar next the pit-bottom, with the longwall places starting at 30 feet from the centre of the shaft. This appeared to be rather a risky method, and in his (the writer's) opinion it would be safer to keep the longwall places about 100 feet away from the shafts.

Mr. William Riddell (Falkirk) wrote that the policy followed by mining engineers generally in this connexion had been to err soundly on the safe side, and everything should be done to secure the winding shaft from damage. He was not satisfied that this would be the case if the practice advocated by Mr. Black were generally adopted. The claims made by Mr. Black in support of his method were threefold, namely (1) economy in driving, (2) better means of ventilation, and (3) a larger output of coal during the period of cutting through the shaft-pillar. Each of these claims was important, but were these advantages sufficient to justify the adoption of a plan so obviously opposed to the methods followed as a result of long experience? He (Mr. Riddell) thought not. If Mr. Black had given comparative figures of the cost of driving by the two methods, it would have been possible to judge whether the economical advantage claimed was real.

With regard to the claim of a better means of ventilation, in any case the ventilation must be adequate, and with the very efficient ventilating appliances of the present day there was no reason that it should not be so. The cost of brattice or air-tubes was a mere detail, and in a short time became insignificant, as the tubes or brattice could be used many times, and after the shaft-pillar forming stage.

With regard to output, this was a consideration that seldom entered into the calculations at this stage of mine operations. The method appeared to have been quite successful in the particular instance described, and there were probably other cases where it would be equally successful; but there were many cases where the result would be serious.

Mr. James Hamilton (Glasgow) said that Mr. Black's difficulty, like that of everybody else, was that of raising the output quickly. It took some considerable time to reach the normal output when forming shaft-pillars in the ordinary way. In a thin seam like that described it ought not to be impossible

to do away with shaft-pillars altogether. The damage to any surface erection through the removal of underlying mineral was reduced by starting directly under that erection and working outwards, keeping the face of the excavation as nearly as possible at equal distances from the building. They were in a position to do that on the completion of a shaft. They got the most advantageous position for doing so, working out the mineral with the minimum of damage. There was a shaft at Kilsyth where no shaft-pillars had been left. He considered that what he suggested was easier now than it had been in the past, because the machinery that was being erected at the surface was probably less liable to serious damage by subsidence—at least, the foundations and other arrangements could be so designed to meet the conditions. In the past shaft pumps with long line-rods were part of every colliery fitting, and these complicated the problem of dealing with subsidence at the shaft. The day of such was now past. Underground pumps, now so common, offered little difficulty. Hydraulic stowing simplified the problem. It might not always be necessary to go to the expense of providing a substitute for coal in the shape of hydraulic stowing; but, if it were, it would not be a serious matter. The pipes used for that purpose might be used for something else afterwards. If the material was not on the spot, the quantity to be provided was not so large as to be a difficulty. Even without hydraulic stowing, he did not think that the removal of the whole coal was an impossibility, and it was worth considering.

The PRESIDENT (Mr. D. M. Mowat) thought that Mr. Dron had touched on the two essential points that required consideration. First, the outside area of any stoop left must be large enough to give protection to the surface buildings which it was intended to support. Having satisfied that consideration, the next was to decide what proportion of coal could be extracted. Mr. Dron had put it at 20 per cent., which was quite an ordinary figure, and was usually accepted as good practice.

The further discussion of the paper was adjourned.

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Mr. HENRY BRIGGS read the following paper on "A Method for the Rapid Estimation of Oxygen and Blackdamp in the Air of Safety-lamp Mines":—

# A METHOD FOR THE RAPID ESTIMATION OF OXYGEN AND BLACKDAMP IN THE AIR OF SAFETY-LAMP MINES.

By HENRY BRIGGS.

*Introduction.*—The problem of providing the underground official with an appliance for measuring approximately the oxygen or blackdamp percentage in the air of naked-light mines has been satisfactorily solved by Dr. J. S. Haldane in his tube-and-taper test.* No description has been published, however, so far as the writer is aware, of a device for the same purpose, suitable for service in a mine where safety-lamps are adopted, and combining the features of simplicity in construction, mechanical strength, speed and simplicity in operation, and absence of liquids: which features seem necessary when the actual circumstances of use are borne in mind.

The arrangement about to be described possesses these features, and provides a means, as the writer believes, of estimating oxygen or blackdamp with a sufficient degree of accuracy for many ordinary purposes. The method is not designed altogether to take the place of chemical analysis of samples collected in the mine; it cannot approach the precision of analysis, which will always be the final appeal in cases of doubt or of special importance. It is an approximate method, intended primarily to assist the fireman in carrying out his statutory duties.

*Description of Device.*—The principle involved is that a safety-lamp will burn with a smaller inlet passage in air rich in oxygen than in air poor in oxygen, and that the size of the inlet can be made a measure of the oxygen percentage.

The appliance (which is illustrated in Figs. 1 to 3) consists of an adjustable cut-off applied to the inlet of a safety-lamp of the improved Gray pattern. The tubes which constitute the usual means of ingress of air to the lamp are stopped, the air being made to enter either through the curved slit *A*, or through

* "A Flame-test for the Estimation of Oxygen and Blackdamp in Naked-light Mines," by J. S. Haldane, *Trans. Inst. M. E.*, 1911, vol. xli., page 455.

the side hole *B* (Fig. 1). When a test for oxygen is being made, the latter hole is closed by the thumb, the air then having only one entrance, namely, the slit *A*. This slit is cut in a well-faced brass plate, over which fits a second plate *C*, of semi-circular shape, and pivoted at its centre. The two plates are held closely together by a small spring. When *C* is rotated by means of the milled knob attached to it, it gradually cuts off the inlet opening and throttles the air-supply to the lamp.

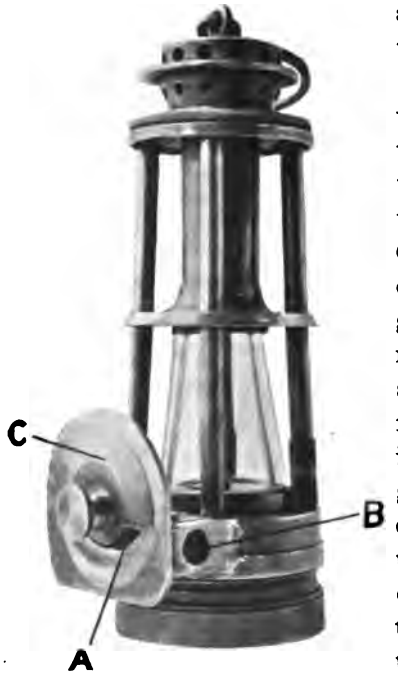



FIG. 1.—A. H. G. LAMP FITTED WITH THE DEVICE.

In Fig. 2, and on the side of the attachment which is turned towards the light, is to be seen the opening *D*, which exposes the back of the movable plate *C* and the graduations which are engraved on it. There are two graduated scales and two index-marks against which the scales are read. These scales are figured from 16·5 to 21, and indicate the percentage of oxygen in the air; the first and outer scale is to be read when the air temperature does not exceed 70° Fahr. (or so), and the second when the temperature is between 70° and 85° Fahr.

Once the oxygen percentage is known, the proportion of blackdamp can readily be calculated, if it should be required. It was, however, decided not to indicate blackdamp as well as oxygen—first, because of possible confusion through having two sets of figures, and, secondly, because oxygen, and not blackdamp, is named in the Act.

The lamp has a single circular wick, and burns benzoline. Spirit fuel is necessary in order to avoid charring of the wick, which would render the method impossible. The attachment does not prevent the lamp from being used as a firedamp indicator; in fact, the lamp, as illustrated, is equally serviceable for estimating either oxygen or firedamp.

*Method of Operation.*—Fig. 3 shows the lamp being used in measuring the oxygen percentage. The operator turns the inlet opening away from him so as to prevent his own breath from entering the lamp and thus vitiating the results. He supports the lamp in his left hand, and closes the side opening (*B*, Fig. 1) with his left thumb. He adjusts the flame to about half its normal height—that is, to $\frac{3}{16}$ or $\frac{1}{4}$ inch or so. An exact adjustment of the flame is unnecessary. With his right hand he turns the plate *C*; he rotates it fairly quickly until the flame sinks and all white light fades from it through lack of air; he then proceeds more carefully, turning the milled knob in short jerks, with a gradually lengthening pause between each jerk, until the flame begins the tremulous flickering or bobbing which is the invariable prelude to its extinction. The operator then lifts his left thumb from the side opening; the flame immediately revives and illuminates the graduations at *D* (Fig. 2); the scale is read, and the oxygen percentage thus obtained.

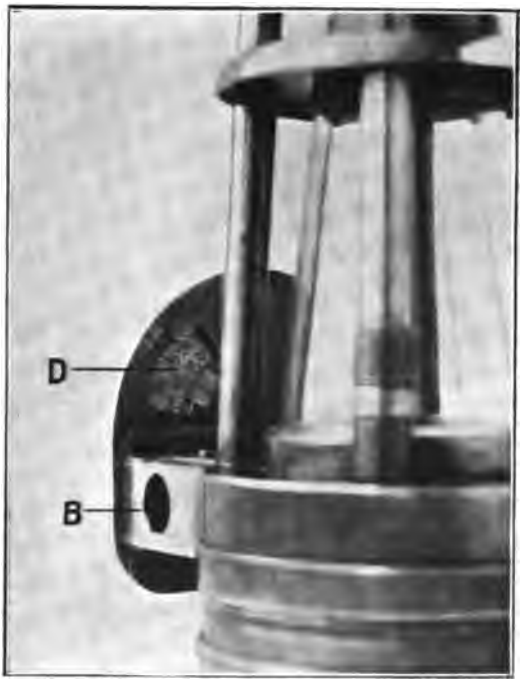



FIG. 2.—ANOTHER VIEW OF THE LAMP, SHOWING THE GRADUATED SCALES.

The fireman, in examining the air of his section as to its oxygen content, is concerned in making sure that a place is "in a fit state for working or passing therein," within the meaning of Section 29 (3) of the Coal Mines Act. That is to say, he is interested rather in knowing whether the air contains more than, or less than, 19 per cent. of oxygen than in measuring the actual

proportion. Because of this, the manner of using the appliance may be simplified still further for the fireman. The scale can be set at 19 per cent., and kept there. If one prefers it, the plates can be held together in this position by a small set-screw. The lamp then normally takes the greater part of its air-supply through the side hole. When the fireman desires to test the air, he lowers the flame to half size and places his thumb on the side hole. If the lamp continues to burn, the air is "up to standard"; he removes his thumb, puts up the flame, and goes on his way. If the flame sinks rapidly, and prepares to go out, the fireman lifts his thumb and recovers the flame; he then knows that the air does not meet the requirements of the Act. Such a test can be made in half a minute; while the determination of the actual percentage in the manner first described occupies from 1 to 2 minutes.

FIG. 3.—ILLUSTRATING THE METHOD OF USING THE DEVICE.

It is hardly necessary to remark that there is no intention or necessity of losing the light in conducting these tests. The official in a safety-lamp mine can in any case be trusted to guard his light for evident reasons. Particularly with the second method just described the risk of being left in the dark is quite small, for not only is a flame showing signs of extinction instantly recoverable; but there is also the fact that it is not often, particularly in safety-lamp mines, that air in which men work or travel contains less than 19 per cent. of oxygen; and with percentages above 19 the flame has no tendency to go out.

An objection to using the lamp in trying whether the requirements of Section 29 of the Act are being maintained is that the Section relates as much to carbon dioxide as to oxygen, and that air in a certain place may be of inferior quality because the carbon dioxide exceeds 1¼ per cent., even though its oxygen content is over 19 per cent. The point is one worth clearing up, as the contention is true enough. A sample of air containing *both* 19 per cent. of oxygen and 1¼ per cent. of carbon dioxide is contaminated by 9·22 per cent. of blackdamp. This blackdamp contains 1·25 parts in 9·22, or 13·5 per cent. of carbon dioxide; the remainder is nitrogen if it be assumed that the analysis is expressed in terms of dry air, and nitrogen *plus* water vapour if it be assumed that it is expressed in terms of damp air. If it were known that the blackdamp occurring in a particular section of the workings in a seam contained more than 13·5 per cent. of carbon dioxide, one would evidently have to be more on one's guard against an excess of this gas than against a diminution of oxygen; the 1·25-per-cent. limit of the Act would be reached before the 19-per-cent. limit.

To take an example at hand: by analysis of the samples taken in the St. Germains Colliery, East Lothian (Table IV.), the blackdamp there present was found to contain, on the average, 15·5 per cent. of carbon dioxide. A simple calculation shows that the air in this case will hold 1·25 per cent. of carbon dioxide when 19·24 per cent. of oxygen is present. Once this is known all difficulty disappears; the fireman can be instructed that air in this section is not up to the statutory requirement unless it contains over 19¼ per cent. of oxygen, and, when the lamp is used, the index will be set at that figure instead of at 19.

Thus, in order to make the lamp most fully serviceable, the composition of the blackdamp should be known, and this involves a few preliminary analyses. The same remark applies to the Haldane tube, and, indeed, to any appliance which gives values for either oxygen or carbon dioxide, but not for both.

*Precautions.*—The following precautions must be observed by a user of the lamp:—

(1) The cut-off must not be moved too quickly. It is important that the working instructions given above should be closely followed.

(2) No reading should be taken until the lamp is hot. A cold lamp gives low values. The lamp should be allowed to burn, with the half-inch working flame, for at least 15 minutes before it is used for the estimation of oxygen.

(3) The gauzes must be kept reasonably clean, and the inlet slit not allowed to become choked.

(4) The size of the test-flame is only of secondary importance. It is preferable, however, not to use a full-sized flame, which is jumpy, and therefore unreliable, when the air-supply is cut down, and normally gives rather high results. The most reliable flame appears to be one of about ¼ inch.

(5) In a strong air-current the inlet opening should be turned towards the return side. Moderate currents have no appreciable influence.

(6) In any place where much water drips from the roof, care should be taken that water does not enter the inlet, or else it may seek the lower gauzes and form films over them, causing the device to give low readings.

*Method of Graduation.*—The scales of the first model were graduated empirically. Blackdamp was made in varying proportions by burning an alcohol flame inside a wooden chamber. Alcohol creates, according to the chemical equation, a blackdamp containing 15 per cent. of carbon dioxide and 85 per cent. of nitrogen. The average of a number of analyses gave the carbon-dioxide constituent as 14·97, a satisfactory verification of the theoretical figure.

Attached to the bottom of the chamber was a short wash-leather sleeve, through which the lamp and one hand could be thrust into the box. A band passing round the sleeve made the latter fit tightly round the wrist, and prevented the mixture in the box from escaping too rapidly. The alcohol flame was made to boil water, so as to keep the atmosphere in the chamber saturated, or almost saturated, with moisture. A hygrometer within the chamber was observed after each lamp-reading had been taken. A small sample bottle was placed on its side inside the box, and when the lamp was introduced care was taken that the air-inlet of the lamp and the mouth of the bottle were close together. A rubber tube, dipping to the bottom of the bottle, was led through a hole in the wall of the chamber. By drawing

one or two lung-fulls of air through the tube, a satisfactory sample was obtained at the moment when the flame was about to go out. The bottle was stoppered and withdrawn, and the sample analysed by the Haldane gas-analysis apparatus. Twenty such determinations allowed a provisional set of graduations to be marked. A preliminary study was then made in order to ascertain whether the temperature of the saturated air had an influence on the results given by the lamp. A striking influence was revealed for high temperature, but no difference of importance was found with temperatures ranging between 40° and 70° Fahr.

The next step was to test thoroughly, by a series of 138 determinations, the scale already marked out, this scale being intended to serve for temperatures below 70° Fahr. Slight adjustments were found necessary in places on the original scale, and these were effected. The figures obtained in this portion of the work are set forth in Table III., to which further reference is made below. The temperature question was then investigated more fully, and the second scale, covering a temperature-range of 70° to 85° Fahr., was set out in the same manner as the first.

*The Influence of Watery Vapour.*—As already stated, the lamp-scales were calibrated in air saturated, or almost saturated, with moisture. The questions now arise: How is the presence of water-vapour to be dealt with? Should the scales be constructed so as to ignore it, as does the ordinary chemical analysis, or should they be made to take it into account?

A chemical analysis, as usually expressed, gives the percentage of the various gases as they would exist if the air were quite free from moisture. It is commonly stated, for example, that fresh air contains 20·93 per cent. of oxygen. This, however, is the figure for dry air, and is not true for atmospheric air, whether in or out of the mine. The air that we breathe always contains some moisture; in mine air, indeed, the percentage of aqueous vapour is seldom, if ever, negligible. To take rather an extreme case, saturated fresh air at 85° Fahr. and normal pressure contains 4 per cent. of water-vapour by volume, and its oxygen percentage is 20·09. The unadjusted result of analysis would, therefore, in this case be 0·84 per cent. in error.

The fact that the results of air analysis are incorrect unless adjusted for the presence of aqueous vapour has been pointed out more than once by Dr. J. S. Haldane; but it is, perhaps, not always realized.

The same authority has also expressed the importance of aqueous vapour, both from the physiological standpoint and from that of its influence on the illuminating power of lamps. With reference to the former he states that—

"From the physiological side also, it is of advantage to have a test which takes into account any abnormally large percentage of moisture in the air, as a man's working capacity tends to become continually diminished as the moisture increases beyond about 2 per cent."*

However the matter may be viewed, one is forced to the conclusion that what is of practical importance is not the oxygen proportion which would have existed in the air if it had been dry (which is the result given by gas analysis), but the percentage which really exists in the air in its actual state.

*The lamp is graduated in such a way that it gives this actual oxygen percentage automatically, and without the need for correction for water-vapour.*

In order to make a comparison with the lamp-readings, all analyses had, therefore, to be corrected for the presence of aqueous vapour. As Glaisher's *Tables* did not have the necessary range, the writer was obliged to construct a table for his own purposes, and as this may be useful to others it is given in Table I.

The instructions for using the table are as follows:—Determine the percentage saturation of the air; note down the vapour pressure (column 2) given opposite the temperature corresponding to the dry-bulb reading; divide the vapour pressure by the barometer reading: multiply the figure so obtained by the percentage saturation; the result is the percentage by volume of aqueous vapour present.

The difference between analyses corrected and uncorrected for water-vapour can be observed from the subsequent tables. Even with comparatively low temperatures, the precision of an analysis is vitiated by neglecting the correction, while with higher temperatures (see Table II.) the error is serious.

The facts that hot air can absorb a greater proportion of aqueous vapour than cold air, and that aqueous vapour has a very pronounced action on a flame, supply reasons why the lamp tends to give continuously lower results as the temperature of the saturated air rises. The influence in question is of no real importance until the temperature exceeds 70° Fahr. Between

* *Op. cit.*, page 458.

70° and 85° Fahr. the effect, although no longer negligible, does not assume extreme proportions, and thus it has been possible approximately to allow for it by providing a second scale on which readings are to be taken when the temperature lies between these limits.

TABLE I.—AQUEOUS VAPOUR IN SATURATED AIR.*

| (1) Temperature. Degs. Fahr. | (2) Vapour pressure, in inches of mercury. | (3) Difference. | (4) Proportion by volume of aqueous vapour; barometer, 30 inches. |
|---|---|---|---|
| | | | Per cent. |
| 32 | 0·181 | | 0·60 |
| 33 | 0·188 | 7 | 0·62 |
| 34 | 0·195 | 7 | 0·65 |
| 35 | 0·203 | 8 | 0·68 |
| 36 | 0·211 | 8 | 0·70 |
| 37 | 0·220 | 9 | 0·73 |
| 38 | 0·229 | 9 | 0·76 |
| 39 | 0·238 | 9 | 0·79 |
| 40 | 0·247 | 9 | 0·82 |
| 41 | 0·256 | 10 | 0·85 |
| 42 | 0·266 | 10 | 0·89 |
| 43 | 0·276 | 10 | 0·92 |
| 44 | 0·287 | 11 | 0·96 |
| 45 | 0·298 | 11 | 0·99 |
| 46 | 0·309 | 12 | 1·03 |
| 47 | 0·321 | 12 | 1·07 |
| 48 | 0·333 | 13 | 1·11 |
| 49 | 0·346 | 14 | 1·15 |
| 50 | 0·360 | 14 | 1·20 |
| 51 | 0·374 | 14 | 1·24 |
| 52 | 0·388 | 14 | 1·29 |
| 53 | 0·402 | 15 | 1·34 |
| 54 | 0·417 | 16 | 1·39 |
| 55 | 0·433 | 16 | 1·44 |
| 56 | 0·449 | 16 | 1·49 |
| 57 | 0·465 | 17 | 1·55 |
| 58 | 0·482 | 17 | 1·60 |
| 59 | 0·499 | 18 | 1·66 |
| 60 | 0·517 | 18 | 1·72 |
| 61 | 0·535 | 19 | 1·78 |
| 62 | 0·554 | 20 | 1·85 |
| 63 | 0·574 | 21 | 1·91 |
| 64 | 0·595 | 21 | 1·98 |
| 65 | 0·616 | 22 | 2·05 |
| 66 | 0·638 | 22 | 2·13 |
| 67 | 0·660 | 23 | 2·20 |
| 68 | 0·683 | 24 | 2·28 |
| 69 | 0·707 | 25 | 2·36 |
| 70 | 0·732 | 25 | 2·44 |
| 71 | 0·757 | 26 | 2·52 |
| 72 | 0·783 | 27 | 2·61 |
| 73 | 0·810 | 28 | 2·70 |
| 74 | 0·838 | 28 | 2·79 |
| 75 | 0·866 | 30 | 2·89 |
| 76 | 0·896 | 30 | 2·99 |
| 77 | 0·926 | 31 | 3·09 |
| 78 | 0·957 | 32 | 3·19 |
| 79 | 0·989 | 33 | 3·30 |
| 80 | 1·022 | 34 | 3·41 |
| 81 | 1·056 | 35 | 3·52 |
| 82 | 1·091 | 36 | 3·64 |
| 83 | 1·127 | 37 | 3·76 |
| 84 | 1·164 | 38 | 3·88 |
| 85 | 1·202 | 39 | 4·01 |
| 86 | 1·241 | 40 | 4·14 |
| 87 | 1·281 | 41 | 4·27 |
| 88 | 1·322 | 42 | 4·41 |
| 89 | 1·364 | 43 | 4·55 |
| 90 | 1·407 | 44 | 4·69 |
| 91 | 1·451 | 45 | 4·84 |
| 92 | 1·496 | 47 | 4·99 |
| 93 | 1·543 | 49 | 5·14 |
| 94 | 1·592 | 52 | 5·31 |
| 95 | 1·644 | 53 | 5·48 |
| 96 | 1·697 | 54 | 5·66 |
| 97 | 1·751 | 55 | 5·84 |
| 98 | 1·806 | 56 | 6·02 |
| 99 | 1·862 | 57 | 6·21 |
| 100 | 1·919 | 58 | 6·40 |
| 101 | 1·977 | 60 | 6·59 |
| 102 | 2·037 | 61 | 6·79 |
| 103 | 2·098 | 63 | 6·99 |
| 104 | 2·161 | 65 | 7·20 |
| 105 | 2·226 | 67 | 7·42 |
| 106 | 2·293 | 69 | 7·64 |
| 107 | 2·362 | 71 | 7·87 |
| 108 | 2·433 | 72 | 8·11 |
| 109 | 2·505 | 73 | 8·35 |
| 110 | 2·578 | 75 | 8·59 |
| 111 | 2·653 | 77 | 8·84 |
| 112 | 2·730 | 79 | 9·10 |
| 113 | 2·809 | 81 | 9·36 |
| 114 | 2·890 | 83 | 9·63 |
| 115 | 2·973 | 85 | 9·91 |
| 116 | 3·058 | 87 | 10·19 |
| 117 | 3·145 | 90 | 10·48 |
| 118 | 3·235 | 92 | 10·78 |
| 119 | 3·327 | 95 | 11·09 |
| 120 | 3·422 | 98 | 11·41 |
| 121 | 3·520 | 101 | 11·73 |
| 122 | 3·621 | | 12·07 |

* Derived from Regnault's experimental data.

As the temperature of the saturated air rises above 85° Fahr., however, the influence of humidity becomes very striking. The

following figures, although relating to air temperatures above those normally existing in mines, are interesting in this connexion. For contrast's sake, the lamp-readings were taken on the ordinary or low-temperature scale. Humidity is indeed so dominant a factor in hot air that if the temperature were raised to a point which appears to lie between 130° and 140° Fahr. the lamp would refuse to burn at all in *fresh* saturated air.

TABLE II.—ILLUSTRATING INFLUENCE OF HOT SATURATED AIR.
Barometer, 29·7 inches.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Hygrometer readings. | | Percentage Saturation. | Aqueous vapour by volume. Per cent. | Oxygen by analysis. Per cent. | Actual oxygen percentage | Lamp-reading. |
| Dry-bulb. Degs. Fahr. | Wet-bulb. Degs. Fahr. | | | | | |
| 97 | 97 | 100 | 5·90 | 20·75 | 19·53 | 17·3 |
| 92 | 92 | 100 | 5·04 | 20·52 | 19·49 | 18·0 |
| 87½ | 86 | 93 | 4·08 | 20·45 | 19·62 | 18·5 |

In the experiments, high temperatures were obtained by introducing pieces of red-hot iron into the test-chamber. These were made to boil water and so maintain saturation.

*Accuracy of the Method.*—Tables III. and IV. provide a sufficient number of readings at ordinary temperatures to allow the precision of the method to be assessed. The manner of obtaining the results entered in Table III. has already been described; and the underground tests set forth in Table IV. will be dealt with below. In Table III. comparison should be made of the figures in columns (8) and (9); in Table IV. the equivalent columns are numbered (6) and (7). The errors of the lamp-readings are recorded in the last columns of the tables, and average errors are stated for each section of the tables. An average error is the arithmetical mean of the individual errors taken regardless of sign. The average error for the whole series of 152 determinations is slightly under $\pm 0{\cdot}24$ per cent.

As can be expected of any method in which "shots" are taken at values, one now and then scores an "outer." It is often possible to explain these aberrant results; but, as they were not obtained intentionally, they cannot be discarded.

TABLE III.—CALIBRATION TESTS IN AIR CONTAMINATED WITH BLACKDAMP OF COMPOSITION $CO_2 : N_2 :: 1 : 5{\cdot}67$; TEMPERATURES BETWEEN 40° and 70° FAHR.

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|
| Number. | Hygrometer readings. Dry-bulb. Degrees Fahr. | Hygrometer readings. Wet-Bulb. Degrees Fahr. | Barometer, in inches. | Percentage of saturation. | Percentage of aqueous vapour. | Oxygen by analysis. Per cent. | Actual oxygen. Per cent. | Lamp-reading. | Error of lamp-reading. |
| 1 | 49 | 48 | 29·7 | 93 | 1·08 | 20·41 | 20·19 | 20·3 | +0·11 |
| 2 | 46½ | 45½ | 29·6 | 93 | 0·96 | 20·42 | 20·22 | 20·0 | −0·22 |
| 3 | 49 | 48½ | 28·9 | 97 | 1·16 | 20·36 | 20·12 | 19·9 | −0·22 |
| 4 | 47 | 47 | 28·9 | 100 | 1·11 | 20·23 | 20·01 | 19·9 | −0·11 |
| 5 | 47 | 46½ | 29·3 | 97 | 1·06 | 20·50 | 20·28 | 20·2 | −0·08 |
| 6 | 47 | 46½ | 29·3 | 97 | 1·06 | 20·54 | 20·32 | 20·1 | −0·22 |
| 7 | 47 | 46½ | 29·3 | 97 | 1·06 | 20·51 | 20·29 | 20·4 | +0·11 |
| 8 | 47 | 46½ | 29·3 | 97 | 1·06 | 20·51 | 20·29 | 20·55 | +0·26 |
| 9 | 47 | 47 | 29·7 | 100 | 1·08 | 20·86 | 20·64 | 20·8 | +0·16 |
| 10 | 47 | 47 | 29·7 | 100 | 1·08 | 20·71 | 20·49 | 20·3 | −0·19 |
| 11 | 47½ | 47½ | 29·7 | 100 | 1·10 | 20·73 | 20·50 | 20·2 | −0·30 |
| 12 | 48½ | 48 | 29·7 | 97 | 1·11 | 20·84 | 20·61 | 20·3 | −0·31 |
| 13 | 48 | 48 | 29·7 | 100 | 1·12 | 20·83 | 20·60 | 20·5 | −0·10 |
| 14 | 49 | 48½ | 29·7 | 97 | 1·13 | 20·84 | 20·60 | 20·2 | −0·40 |
| 15 | 49½ | 49 | 29·7 | 97 | 1·15 | 20·72 | 20·48 | 20·1 | −0·38 |
| 16 | 50 | 49½ | 29·7 | 96 | 1·16 | 20·63 | 20·39 | 20·05 | −0·34 |
| 17 | 50 | 49½ | 29·7 | 96 | 1·16 | 20·86 | 20·62 | 21·0 | +0·38 |
| 18 | 50 | 49½ | 29·7 | 96 | 1·16 | 20·77 | 20·53 | 20·5 | −0·03 |
| 19 | 51 | 50 | 29·7 | 94 | 1·17 | 20·68 | 20·44 | 20·4 | −0·04 |
| 20 | 51 | 50½ | 29·7 | 97 | 1·21 | 20·58 | 20·33 | 20·2 | −0·13 |
| 21 | 57 | 56½ | 29·9 | 97 | 1·51 | 20·50 | 20·19 | 19·9 | −0·29 |
| 22 | 57 | 57 | 29·9 | 100 | 1·56 | 20·56 | 20·24 | 20·5 | +0·26 |
| 23 | 58 | 57½ | 29·9 | 97 | 1·56 | 20·50 | 20·19 | 20·7 | +0·51 |
| 24 | 58 | 58 | 29·9 | 100 | 1·61 | 20·47 | 20·14 | 19·95 | −0·19 |
| 25 | 58½ | 58½ | 29·9 | 100 | 1·64 | 20·38 | 20·05 | 20·2 | +0·15 |
| 26 | 63 | 62½ | 29·9 | 97 | 1·86 | 20·82 | 20·43 | 21·0 | +0·57 |
| 27 | 63 | 63 | 29·9 | 100 | 1·92 | 20·75 | 20·36 | 20·7 | +0·34 |
| 28 | 64 | 64 | 29·9 | 100 | 1·99 | 20·62 | 20·21 | 19·6 | −0·61 |
| 29 | 61 | 54½ | 29·3 | 63½ | 1·16 | 20·93 | 20·69 | 20·7 | +0·01 |
| | Average error, 20 to 20·7 per cent., ± 0·24 per cent. | | | | | | | | |
| 30 | 57 | 56½ | 29·9 | 97 | 1·51 | 19·58 | 19·28 | 19·15 | −0·13 |
| 31 | 57 | 56½ | 29·9 | 97 | 1·51 | 19·82 | 19·52 | 19·25 | −0·27 |
| 32 | 57 | 57 | 29·9 | 100 | 1·56 | 19·99 | 19·68 | 19·45 | −0·23 |
| 33 | 57½ | 57 | 29·9 | 97 | 1·53 | 20·13 | 19·82 | 19·25 | −0·57 |
| 34 | 57½ | 57 | 29·9 | 97 | 1·53 | 20·15 | 19·84 | 19·25 | −0·59 |
| 35 | 58 | 57½ | 29·9 | 97 | 1·56 | 20·27 | 19·95 | 19·75 | −0·20 |
| 36 | 63½ | 62½ | 29·3 | 94 | 1·88 | 19·43 | 19·06 | 19·0 | −0·00 |
| 37 | 63½ | 62½ | 29·3 | 94 | 1·88 | 19·51 | 19·14 | 19·2 | +0·06 |
| 38 | 63½ | 62½ | 29·3 | 94 | 1·88 | 19·60 | 19·23 | 19·3 | +0·07 |
| 39 | 69 | 67½ | 29·7 | 92 | 2·19 | 20·21 | 19·77 | 19·5 | −0·27 |
| 40 | 68 | 67 | 29·7 | 94 | 2·16 | 20·20 | 19·76 | 19·35 | −0·41 |
| 41 | 66½ | 65 | 29·7 | 91 | 1·98 | 20·16 | 19·76 | 19·55 | −0·21 |
| 42 | 47½ | 47 | 29·0 | 96 | 1·07 | 20·21 | 19·99 | 20·3 | +0·31 |
| 43 | 51½ | 51 | 29·0 | 97 | 1·27 | 19·80 | 19·55 | 19·9 | +0·35 |
| 44 | 49 | 48½ | 28·9 | 97 | 1·16 | 19·72 | 19·49 | 19·8 | +0·31 |
| 45 | 50 | 49½ | 28·9 | 97 | 1·21 | 20·17 | 19·93 | 20·1 | +0·17 |
| 46 | 47½ | 47½ | 29·3 | 100 | 1·13 | 20·05 | 19·82 | 20·1 | +0·28 |
| 47 | 48 | 47½ | 29·3 | 97 | 1·10 | 20·07 | 19·85 | 20·1 | +0·25 |
| 48 | 48 | 47½ | 29·3 | 97 | 1·10 | 20·03 | 19·81 | 19·8 | −0·01 |

TABLE III.—*Continued.*—CALIBRATION TESTS IN AIR CONTAMINATED WITH BLACK-DAMP OF COMPOSITION $CO_2 : N_2 :: 1 : 5{\cdot}67$; TEMPERATURES BETWEEN 40° AND 70° FAHR.

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|
| Number. | Hygrometer readings. Dry-bulb. Degrees Fahr. | Hygrometer readings. Wet-bulb. Degrees Fahr. | Barometer, in inches. | Percentage of saturation. | Percentage of aqueous vapour. | Oxygen by analysis. Per cent. | Actual oxygen. Per cent. | Lamp-reading. | Error of lamp-reading. |
| 49 | 48½ | 48 | 29·3 | 97 | 1·13 | 20·12 | 19·89 | 20·05 | +0·16 |
| 50 | 49 | 48 | 29·8 | 93 | 1·08 | 19·87 | 19·66 | 20·0 | +0·34 |
| 51 | 48 | 48 | 29·8 | 100 | 1·04 | 19·55 | 19·33 | 19·8 | +0·47 |
| 52 | 49 | 48½ | 29·7 | 97 | 1·13 | 20·07 | 19·84 | 19·1 | −0·74 |
| 53 | 50½ | 50 | 29·0 | 97 | 1·26 | 19·59 | 19·34 | 19·65 | +0·31 |
| 54 | 51 | 50 | 29·6 | 94 | 1·18 | 19·28 | 19·05 | 19·2 | +0·15 |
| 55 | 51 | 50 | 29·6 | 94 | 1·18 | 19·55 | 19·32 | 19·0 | −0·32 |
| 56 | 48 | 47 | 29·0 | 93 | 1·07 | 19·71 | 19·50 | 19·1 | −0·40 |
| 57 | 50½ | 50 | 29·0 | 97 | 1·26 | 19·59 | 19·34 | 19·45 | +0·11 |
| 58 | 49½ | 49 | 28·9 | 97 | 1·18 | 19·86 | 19·63 | 19·7 | +0·07 |
| 59 | 49 | 48½ | 28·9 | 97 | 1·16 | 19·92 | 19·69 | 19·3 | −0·39 |
| 60 | 50 | 50 | 28·9 | 100 | 1·24 | 19·28 | 19·04 | 18·9 | −0·14 |
| 61 | 51 | 51 | 28·9 | 100 | 1·29 | 19·29 | 19·04 | 18·9 | −0·14 |
| 62 | 47½ | 47 | 29·3 | 96 | 1·08 | 19·73 | 19·52 | 19·1 | −0·42 |
| 63 | 48 | 47½ | 29·3 | 97 | 1·10 | 19·63 | 19·41 | 18·8 | −0·61 |
| 64 | 49 | 48 | 29·7 | 93 | 1·08 | 19·41 | 19·20 | 19·3 | +0·10 |
| 65 | 49 | 48 | 29·7 | 93 | 1·08 | 19·50 | 19·29 | 19·4 | +0·11 |
| 66 | 50 | 50 | 29·8 | 100 | 1·21 | 20·07 | 19·83 | 19·4 | −0·43 |
| 67 | 51 | 51 | 29·8 | 100 | 1·25 | 20·05 | 19·80 | 19·5 | −0·30 |
| 68 | 51½ | 50 | 29·8 | 97 | 1·24 | 20·17 | 19·92 | 19·5 | −0·42 |
| 69 | 51½ | 51 | 29·8 | 97 | 1·24 | 20·11 | 19·86 | 19·5 | −0·36 |
| 70 | 47 | 47 | 29·8 | 100 | 1·08 | 19·55 | 19·34 | 18·8 | −0·54 |
| | Average error, 19 to 20 per cent., ± 0·28 per cent. | | | | | | | | |
| 71 | 48 | 47 | 29·0 | 93 | 1·07 | 19·07 | 18·87 | 19·1 | +0·23 |
| 72 | 53½ | 53½ | 28·9 | 100 | 1·42 | 18·67 | 18·41 | 18·75 | +0·34 |
| 73 | 52 | 52 | 29·5 | 100 | 1·32 | 18·33 | 18·09 | 18·75 | +0·66 |
| 74 | 53½ | 53 | 29·5 | 97 | 1·34 | 18·63 | 18·38 | 18·75 | +0·37 |
| 75 | 53 | 53 | 29·5 | 100 | 1·37 | 18·54 | 18·29 | 18·85 | +0·56 |
| 76 | 49 | 49 | 29·85 | 100 | 1·16 | 18·68 | 18·46 | 18·9 | +0·44 |
| 77 | 49 | 49 | 29·85 | 100 | 1·16 | 19·14 | 18·92 | 18·8 | −0·12 |
| 78 | 58 | 58 | 29·9 | 100 | 1·61 | 18·79 | 18·49 | 18·35 | −0·14 |
| 79 | 58 | 57½ | 29·9 | 97 | 1·56 | 19·10 | 18·80 | 18·65 | −0·15 |
| 80 | 63½ | 62½ | 29·3 | 94 | 1·88 | 18·47 | 18·12 | 18·0 | −0·12 |
| 81 | 63 | 62 | 29·3 | 94 | 1·84 | 18·83 | 18·48 | 18·7 | +0·22 |
| 82 | 62½ | 62 | 29·3 | 97 | 1·86 | 19·10 | 18·74 | 19·0 | +0·26 |
| 83 | 63 | 62 | 29·3 | 94 | 1·84 | 19·33 | 18·97 | 19·0 | +0·03 |
| 84 | 67 | 66 | 29·3 | 94 | 2·11 | 18·55 | 18·16 | 18·0 | −0·16 |
| 85 | 54½ | 54 | 29·7 | 96 | 1·37 | 18·30 | 18·05 | 17·9 | −0·15 |
| 86 | 50 | 49½ | 29·7 | 96 | 1·17 | 19·21 | 18·99 | 18·55 | −0·44 |
| 87 | 53 | 52 | 29 6 | 94 | 1·28 | 18·35 | 18·12 | 17·8 | −0·32 |
| 88 | 53½ | 53 | 28·9 | 97 | 1·38 | 18·52 | 18·26 | 18·1 | −0·16 |
| 89 | 50 | 50 | 29·3 | 100 | 1·23 | 18·75 | 18·52 | 18·55 | +0·03 |
| 90 | 50½ | 50 | 29·3 | 97 | 1·21 | 18·62 | 18·40 | 18·6 | +0·20 |
| 91 | 51 | 50½ | 29·3 | 97 | 1·23 | 18·85 | 18·62 | 18·4 | −0·22 |
| 92 | 51 | 51 | 29·3 | 100 | 1·27 | 18·84 | 18·60 | 18·5 | −0·10 |
| 93 | 52 | 52 | 29·5 | 100 | 1·32 | 18·43 | 18·19 | 18·45 | +0·26 |
| 94 | 52 | 52 | 29·7 | 100 | 1·31 | 18·31 | 18·07 | 17·7 | −0·37 |
| | Average error, 18 to 19 per cent., ± 0·25 per cent. | | | | | | | | |

TABLE III.—*Continued.*—CALIBRATION TESTS IN AIR CONTAMINATED WITH BLACKDAMP OF COMPOSITION $CO_2 : N_2 :: 1 : 5{\cdot}67$; TEMPERATURES BETWEEN 40° AND 70° FAHR.

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|
| Number. | Hygrometer readings. Dry-bulb. Degrees Fahr. | Hygrometer readings. Wet-bulb. Degrees Fahr. | Barometer, in inches. | Percentage of saturation. | Percentage of aqueous vapour. | Oxygen by analysis. Per cent. | Actual oxygen. Per cent. | Lamp-reading. | Error of lamp-reading. |
| 95 | 51 | 50 | 29·0 | 94 | 1·20 | 17·68 | 17·47 | 17·75 | +0·28 |
| 96 | 53 | 53 | 28·9 | 100 | 1·39 | 17·68 | 17·43 | 17·75 | +0·32 |
| 97 | 53½ | 53 | 28·9 | 97 | 1·38 | 18·12 | 17·87 | 18·45 | +0·58 |
| 98 | 54 | 53 | 29·3 | 94 | 1·35 | 18·04 | 17·80 | 17·8 | nil |
| 99 | 52½ | 52½ | 29·7 | 100 | 1·33 | 17·64 | 17·42 | 17·75 | +0·33 |
| 100 | 50 | 50 | 29·8 | 100 | 1·21 | 17·73 | 17·52 | 18·05 | +0·53 |
| 101 | 51 | 51 | 29·8 | 100 | 1·25 | 18·15 | 17·92 | 18·05 | +0·13 |
| 102 | 52 | 52 | 29·5 | 100 | 1·32 | 18·21 | 17·97 | 17·95 | −0·02 |
| 103 | 54 | 54 | 29·7 | 100 | 1·41 | 17·17 | 16·93 | 17·0 | +0·07 |
| 104 | 55 | 54½ | 29·7 | 97 | 1·42 | 17·77 | 17·52 | 17·3 | −0·22 |
| 105 | 53 | 53 | 29·7 | 100 | 1·36 | 17·44 | 17·20 | 17·25 | +0·05 |
| 106 | 51 | 50 | 29·6 | 94 | 1·18 | 17·45 | 17·34 | 17·3 | −0·04 |
| 107 | 51 | 51 | 29·6 | 100 | 1·26 | 17·75 | 17·53 | 17·5 | −0·03 |
| 108 | 52½ | 52 | 29·6 | 96 | 1·23 | 18·14 | 17·92 | 17·6 | −0·32 |
| 109 | 52 | 51½ | 29·0 | 97 | 1·30 | 17·80 | 17·57 | 17·55 | −0·02 |
| 110 | 52 | 52 | 29·0 | 100 | 1·35 | 18·19 | 17·95 | 17·5 | −0·45 |
| 111 | 53 | 53 | 29·0 | 100 | 1·40 | 18·11 | 17·86 | 17·55 | −0·31 |
| 112 | 53 | 53 | 29·3 | 100 | 1·38 | 17·56 | 17·32 | 17·65 | +0·33 |
| 113 | 52½ | 52 | 29·3 | 96 | 1·30 | 17·25 | 17·03 | 17·45 | +0·42 |
| 114 | 52½ | 52 | 29·3 | 96 | 1·30 | 17·59 | 17·36 | 17·55 | +0·19 |
| 115 | 53 | 52½ | 29·3 | 97 | 1·34 | 17·82 | 17·58 | 17·7 | +0·12 |
| 116 | 51 | 51 | 29·7 | 100 | 1·26 | 17·71 | 17·49 | 17·35 | −0·14 |
| 117 | 51 | 51 | 29·7 | 100 | 1·26 | 17·22 | 17·00 | 16·8 | −0·20 |
| 118 | 54 | 53 | 29·7 | 94 | 1·33 | 17·52 | 17·29 | 17·5 | +0·21 |
| 119 | 52 | 52 | 29·5 | 100 | 1·32 | 17·62 | 17·38 | 17·2 | −0·18 |
| 120 | 52 | 52 | 29·5 | 100 | 1·32 | 17·80 | 17·56 | 17·5 | −0·06 |
| 121 | 54 | 53 | 29·5 | 94 | 1·34 | 17·35 | 17·12 | 17·45 | +0·33 |
| 122 | 59½ | 59 | 29·9 | 97 | 1·65 | 17·01 | 16·73 | 17·2 | +0·47 |
| 123 | 59 | 58½ | 29·9 | 97 | 1·62 | 18·00 | 17·71 | 17·6 | −0·11 |
| 124 | 58 | 57½ | 29·9 | 97 | 1·56 | 18·28 | 17·99 | 17·8 | −0·19 |
| 125 | 52½ | 52 | 29·85 | 97 | 1·28 | 17·43 | 17·22 | 17·1 | −0·12 |
| 126 | 53 | 52½ | 29·85 | 97 | 1·31 | 17·10 | 16·87 | 16·75 | −0·12 |
| 127 | 55½ | 55 | 29·85 | 97 | 1·43 | 17·10 | 16·86 | 17·05 | +0·19 |
| 128 | 56 | 56 | 29·85 | 100 | 1·50 | 17·10 | 16·84 | 16·5 | −0·34 |
| 129 | 56½ | 56 | 29·85 | 97 | 1·48 | 16·68 | 16·43 | 16·8 | +0·37 |
| 130 | 54 | 53 | 29·85 | 93 | 1·30 | 17·86 | 17·64 | 17·7 | +0·06 |
| 131 | 59½ | 58½ | 29·85 | 93 | 1·58 | 17·10 | 16·83 | 16·7 | −0·13 |
| 132 | 62½ | 62½ | 29·85 | 100 | 1·89 | 17·60 | 17·27 | 17·15 | −0·12 |
| 133 | 62½ | 62½ | 29·85 | 100 | 1·89 | 18·05 | 17·71 | 17·75 | +0·04 |
| 134 | 67 | 66½ | 29·3 | 97 | 2·18 | 17·46 | 17·08 | 17·1 | +0·02 |
| 135 | 68 | 67½ | 29·3 | 97 | 2·26 | 17·83 | 17·43 | 17·2 | −0·23 |
| 136 | 68 | 67 | 29·3 | 94 | 2·19 | 18·33 | 17·93 | 17·7 | −0·23 |
| 137 | 63½ | 62½ | 29·3 | 94 | 1·88 | 18·05 | 17·71 | 17·3 | −0·41 |
| 138 | 62 | 62 | 29·85 | 100 | 1·86 | 18·34 | 17·99 | 18·0 | +0·01 |

Average error, 16·5 to 18 per cent., ± 0·21 per cent.

An analysis of the errors revealed by Tables III. and IV. is as follows:—

| Magnitude of errors. Per cent. | | | | Frequency of errors. Readings. | Per cent. |
|---|---|---|---|---|---|
| Over | | | 0·7 | 1 in 152, or | 0·7 |
| Between | 0·6 | and | 0·7 | 3 ,, 152, ,, | 1·9 |
| ,, | 0·5 | ,, | 0·6 | 8 ,, 152, ,, | 5·3 |
| ,, | 0·4 | ,, | 0·5 | 14 ,, 152, ,, | 9·2 |
| ,, | 0·3 | ,, | 0·4 | 29 ,, 152, ,, | 19·1 |
| ,, | 0·2 | ,, | 0·3 | 27 ,, 152, ,, | 17·8 |
| Under | | | 0·2 | 70 ,, 152, ,, | 46·0 |

The accuracy of the high-temperature scale was also tested by a considerable number of readings, which went to show that it gives values, automatically corrected for water-vapour, with much the same order of precision as the first or low-temperature scale.

Table IV.—Results of Tests at St. Germains Colliery, East Lothian. Barometer, 29·55 inches.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| Number. | Hygrometer readings. Dry-bulb. | Wet-bulb. | Percentage of saturation. | Percentage of aqueous vapour. | Oxygen by analysis. | Actual oxygen percentage. | Lamp-reading. | Haldane tube-reading. | Error of lamp-reading. |
| A | 52 | 50 | 87 | 1·14 | 20·73 | 20·49 | 20·4 | 20·9 | −0·09 |
| B | 53½ | 51 | 84 | 1·16 | 20·47 | 20·23 | 20·2 | Not taken | −0·03 |
| C | 53½ | 52 | 90 | 1·24 | 20·07 | 19·82 | 19·9 | Not taken | +0·08 |
| D | 55½ | 55 | 97 | 1·45 | 19·88 | 19·59 | (*a*)19·2<br>(*b*)19·3 | 19·5 | (*a*) −0·39<br>(*b*) −0·29 |
| E | 58 | 56 | 87 | 1·42 | 19·56 | 19·28 | 19·1 | (*a*)19·6<br>(*b*)19·6 | −0·18 |
| F | 57½ | 56 | 90 | 1·44 | 19·54 | 19·26 | (*a*)19·2<br>(*b*)19·1 | (*a*)19·7<br>(*b*)19·4 | (*a*) −0·06<br>(*b*) −0·16 |
| G | 57½ | 55½ | 87 | 1·39 | 19·47 | 19·20 | (*a*)18·8<br>(*b*)18·9 | (*a*)18·8<br>(*b*)19·4 | (*a*) −0·40<br>(*b*) −0·30 |
| H | 59 | 57½ | 90 | 1·52 | 18·86 | 18·56 | 18·75 | 18·8 | +0·19 |
| I | 58 | 56½ | 90 | 1·47 | 17·46 | 17·20 | 17·3 | Too low for tube | +0·10 |
| J | 56 | 55 | 94 | 1·43 | 19·64 | 19·36 | (*a*)19·25<br>(*b*)19·1 | (*a*)20·3<br>(*b*)20·1 | (*a*) −0·11<br>(*b*) −0·26 |

Average error of lamp-reading, ± 0·19 per cent.

*Underground Tests.*—Through the kindness of Mr. Hugh Waddell, the writer was able to make a useful set of underground tests. The tests were conducted in the Four-Foot Seam at St. Germains Colliery, in workings which have been temporarily abandoned. Those trials indicating least oxygen were made in a stone-mine in which the air was stagnant. The lower part of this mine was full of blackdamp. A sample was taken during each trial, and afterwards analysed. In order to correct the

analyses for water-vapour, hygrometric readings were also booked. Determinations with the Haldane tube were made at most of the points. Mr. Waddell took the majority of the latter readings, his value occasionally being checked by others present.

The results are recorded in Table IV. Columns (6) and (7) should be compared together; also columns (5) and (8). The average error of the lamp-readings is $\pm 0{\cdot}19$ per cent. The device appears to give more satisfactory results in the pit than in the laboratory, possibly because in the larger volumes of the pit the air is not being changed appreciably by the products of combustion of the lamp itself, and therefore is less subject to fluctuation in quality during an experiment.

*The Influence of Variations in the Composition of Blackdamp.*—As is now well-known, the blackdamp of mines consists principally of nitrogen. The ratio between nitrogen and carbon dioxide is very variable, and it was necessary to ascertain whether this variability would have any influence of importance on the readings given by the lamp. The device was graduated and tested in air polluted with blackdamp of the composition $N_2 : CO_2 :: 5{\cdot}67 : 1$. A series of observations was first taken in air containing various percentages of pure nitrogen, and analyses were made of every sample of air. No distinction whatever could be drawn between blackdamp of pure nitrogen and the blackdamp used in the original calibration. Any difference which might exist in the effects on the lamp of these two kinds of blackdamp is certainly considerably less than the experimental error.

The effect of pure carbon dioxide was next investigated; and this proved more marked, the lamp giving low readings. The following figures summarize the results of this section of the work, all readings being on the low-temperature scale:—

TABLE V.—AIR CONTAMINATED WITH PURE CARBON DIOXIDE.

| Average temperature, 47 degrees Fahr. | Average relative humidity, 93 per cent. | |
|---|---|---|
| Percentage of oxygen: corrected for aqueous vapour. | Lamp-reading. | Difference. |
| 20·7 | 20·7 | Nil. |
| 20·0 | 19·55 | 0·45 |
| 19·5 | 18·8 | 0·70 |
| 19·0 | 18·05 | 0·95 |
| 18·5 | 17·45 | 1·05 |
| 18·0 | 16·85 | 1·15 |

As blackdamp consisting solely of carbon dioxide is unknown in British mines, these results have, at first sight, only a theoretical value. They, however, assist us to judge as to the size of the correction which requires to be applied to the lamp-readings when the lamp is used in air containing blackdamp richer than usual in carbon dioxide.

It is now necessary to enquire what meaning can be attached to the words "richer than usual," and to find out, indeed, what is the composition of the blackdamp richest in carbon dioxide which is likely to be met with in British mines. In order to reach a decision on this point, the results recorded in Table VI. were collected.

We may conclude from this table that the device will have to face air polluted with blackdamps of all constitutions between almost pure nitrogen and one bearing almost 50 per cent. of carbon dioxide. No correction whatever needs to be applied to the lamp-readings with blackdamps, the carbon-dioxide proportions of which range between zero and 25 per cent.- and this range includes the vast majority. When the carbon-dioxide proportion rises to 40 per cent., the lamp reads 19 instead of 19·28. When the proportion reaches 50 per cent., the 19 mark is 0·35 per cent. in error.

Except in very extreme cases, therefore, alteration in the composition of the blackdamp present has a negligible influence on the lamp values.

*The Influence of Firedamp.*—Since the device is intended for use in safety-lamp mines, the possible interference of firedamp cannot be overlooked. In investigating this matter, it was considered unnecessary to deal with proportions of inflammable gas exceeding 2½ per cent., since at that percentage men have to be withdrawn, and the oxygen question becomes subsidiary. As the gas-proportions are thus small, and as the tests were concerned not with the gas-indications, but solely with the effect of inflammable gas upon oxygen estimation, it was considered permissible to use coal-gas to represent firedamp. A number of experiments were carried out with the lamp in a long, narrow box, through which was made to flow a steady current of air containing various proportions of blackdamp and percentages of inflammable gas ranging from zero to 2½. Samples were taken in the usual way, withdrawn and analysed.

TABLE VI.—RANGE IN COMPOSITION OF BLACKDAMP, AS ASCERTAINED FROM PUBLISHED ANALYSES OF MINE AIR.

| Sources of information. | Number of results consulted. | Mean composition of blackdamp. | | Blackdamp containing minimum of carbon dioxide. | | Blackdamp containing maximum of carbon dioxide. | | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | Nitrogen. Per cent. | Carbon dioxide. Per cent. | Nitrogen. Per cent. | Carbon dioxide. Per cent. | Nitrogen. Per cent. | Carbon dioxide. Per cent. | |
| Dr. J. S. Haldane and W. N. Atkinson, "Investigations on the Composition, Occurrence and Properties of Blackdamp," *Trans. Inst. M. E.*, 1895, vol. viii., page 549 ... | 8 | 87·04 | 12·96 | 91·37 | 8·63 | 85·30 | 14·70 | |
| Prof. John Cadman, *Reports of an Enquiry into the Ventilation of Coal Mines, etc,"* 1909 [Cd. 4551] ... ... ... | 273 | 90·06 | 9·94 | 98·27 | 1·73 (*a*) | 78·13 | 21·87 (*b*) | (*a*) Page 29 : sample from intake. (*b*) Page 26 : sample from working-place ; drift in solid coal. |
| E. B. Whalley, *Ibid.* ... ... | 136 | 89·46 | 10·54 (*a*) | 97·80 | 2·20 (*b*) | 79·04 | 20·96 (*c*) | Samples all taken in Scottish collieries. (*a*) Page 67. (*b*) Page 85 : sample from intake. (*c*) Page 81: sample from longwall-face. |
| E. B. Whalley, *Ibid.* ... ... | 19 | 84·86 | 15·14 (*a*) | 98·55 | 1·45 (*b*) | 56·10 | 43·90 (*c*) | Samples all taken in two Scottish oil-shale mines. (*a*) Page 67. (*b*) Page 88 : sample from intake. (*c*) Page 89 : cross-measure drift. |
| Prof. Thomas Gray, "Analyses of Samples of Air from Representative Mines in Scotland," *Trans. Inst. M. E.*, 1910, vol. xxxix., page 305 .. ... | 29 (*a*) | 88·76 | 11·24 | 93·7 | 6·3 (*b*) | 82·1 | 17·9 (*c*) | (*a*) Blackdamp calculated only for these analyses containing 0·5 per cent., or more, of carbon dioxide (*b*) No. 50, page 309 : return in Chemiss coal. (*c*) No. 57, page 310 : return in Dunfermline Splint. |

The results were unexpected. It was found that inflammable gas causes the lamp to give high readings. *The lamp, in fact, disregards entirely the presence of the gas, and treats it as though it were so much air.* For example, in saturated air containing a little firedamp and no blackdamp, the lamp gives the oxygen-value for perfectly fresh saturated air. This effect is barely noticeable when the firedamp proportion is below that unmistakeably discernible on the lowered flame of the lamp (that is, below about 1¼ per cent.), and can then be disregarded. But with firedamp percentages between 1¼ and 2½, the gas must first be estimated by means of the "cap," and then one-fifth of its value deducted from the lamp-reading for oxygen, in order to correct the latter for its presence.

The following series of results (Table VII.) is selected from several similar sets:—

TABLE VII.—AIR CONTAMINATED WITH BOTH BLACKDAMP AND INFLAMMABLE GAS.

| Mean temperature, 48° Fahr. Mean relative humidity, 90 per cent. | | | | | |
|---|---|---|---|---|---|
| Results of analysis: corrected for aqueous vapour. | | Lamp-reading. | Error of lamp-reading before correction. | Lamp-reading *minus* ⅕ inflammable gas. | Error of lamp-reading after correction. |
| Inflammable gas. | Oxygen. | | | | |
| Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| 2·47 | 18·85 | 19·50 | +0·65 | 19·0 | +0·15 |
| 2·23 | 18·68 | 19·25 | +0·57 | 18·8 | +0·12 |
| 1·98 | 18·80 | 19·15 | +0·35 | 18·75 | −0·05 |
| 1·73 | 18·68 | 18·95 | +0·27 | 18·6 | −0·08 |
| 1·48 | 18·80 | 19·00 | +0·20 | 18·7 | −0·10 |
| 1·24 | 18·90 | 18·95 | +0·05 | 18·7 | −0·20 |
| 0·99 | 18·96 | 19·05 | +0·09 | 18·85 | −0·11 |

*Extension of the Method.*—This method of determining the oxygen percentage is not limited to proportions between 16·5 and 21, although that range is probably sufficient for everyday purposes. The first model, for instance, was graduated up to 35 per cent. of oxygen; while, if the hydrogen-flame were employed, as in the Clowes lamp, the range of the readings could be extended in the other direction to the neighbourhood of 9 per cent.

Mr. JOHN MASTERTON (H.M. Inspector of Mines, Edinburgh) asked whether the principle that Mr. Briggs had so fully explained in his paper could be successfully applied to other types of safety-lamps, because the Hepplewhite-Gray lamp was very seldom used by firemen in East Scotland. Mr. Briggs's device had to be fitted to a lamp with a fixed inlet, and he wondered whether the principle could be applied to a safety-lamp with a deflector ring, in which there was certainly a fixed inlet inside the bonnet. The ring effectively separated the intake air from the products of combustion, and if there were an annular ring with graduated opening and scale outside the bonnet of the lamp, it should serve the purpose. As for the test, when a fireman had adjusted his lamp to the conditions of his district, he should fix the disc at the 19-per-cent. oxygen mark, and leave it there. That would be much better, he thought, than if the fireman were to move his disc about (and he could find all that he required in less time), as in doing this he would be very apt to extinguish his light. He felt that the reason why sometimes small quantities of firedamp were not reported to them was the fear the fireman had of losing his light. If the fireman, who in East Scotland had to test both for firedamp and lack of oxygen, had the fear of losing his light through a delicate test for oxygen deficiency, it might make him chary of testing as closely as he ought to. Of course, there was a remedy for all that, but under the present Coal Mines Act and Regulations it was not lawful, and could not therefore be used. The remedy was that of allowing the firemen—certainly not the miners—to relight their lamps by internal igniters, and he felt sure that if that were allowed, better results would be obtained from the inspections by firemen. It seemed to him that it would be an advantage if the principle which Mr. Briggs had described could be applied to some of the lamps more commonly used in Scotland. He thanked Mr. Briggs for bringing his device to their notice, and he would be glad to test it as opportunity arose.

Mr. JOHN SIM (Edinburgh) said that, as blackdamp was really a mixture of carbon dioxide and nitrogen, the author ought not to have used the term "blackdamp"; but should have called the mixture carbon dioxide and nitrogen.

Mr. HENRY BRIGGS, in reply to the last remark, said that the

constitution of blackdamp, as a mixture of nitrogen and carbon dioxide, was dealt with in the paper. "Blackdamp" was a term that had been used by miners for many generations; it had a real significance to them, manifested by its action on a light. It was inadvisable, and would be a waste of time, to consider the abolition of the word.

He thanked Mr. Masterton for his remarks. The possibility of applying the same principle to a deflector lamp had been engaging his attention since a conversation, some weeks ago, with Mr. Masterton. Besides the fact that a deflector lamp was more commonly used than an A.H.G. lamp, there would be the advantage that a shut-off of the ring pattern, fitted round the lower part of the bonnet, would not obstruct the light of the lamp to the same degree as the arrangement illustrated in the paper. There was, however, the drawback that the shut-off in such a position would get hot, and besides the unpleasantness of having to move a hot ring there was the fear, to his (Mr. Briggs's) mind of the mechanical difficulty in obtaining a close fit between the metal surfaces. Warping was apt to take place on heating metal. This point could only be settled by trial, and it was well worth while his going into it.

He fully appreciated Mr. Masterton's remarks as to the help that would be afforded to the fireman if the internal igniter were permissible, and, as a matter of fact, the first model (shown to the members) was fitted with a Wolf igniter. In subsequent models, however, the regulations being what they were, no igniter would be attached. In order to add the Wolf igniter to the A.H.G. lamp a certain modification of the usual lamp-bottom had to be made; then the device became perfectly practicable.

The further discussion of the paper was adjourned.

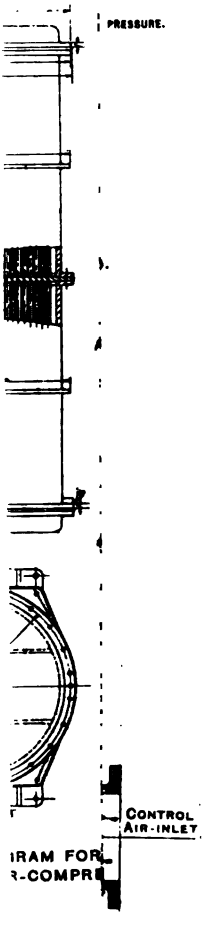
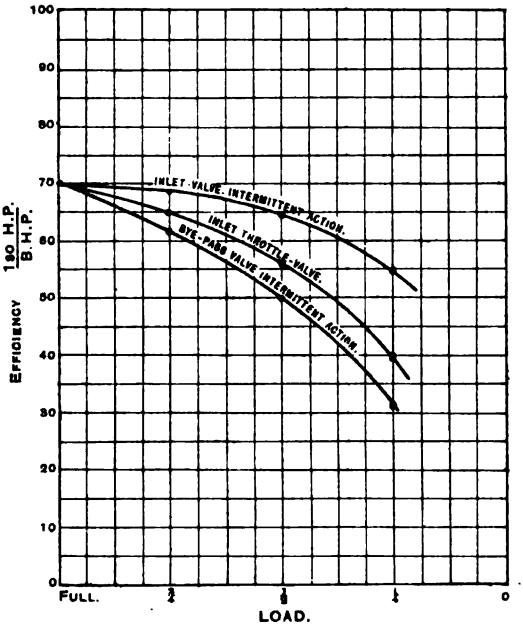



FIG. 15.—EFFICIENCY CURVES AT VARIOUS LOADS.




FIGS. 16 AND 17.—AIR-CYLINDER DIAGRAMS.

FIG. 16.—LEAKY SUCTION-VALVE.

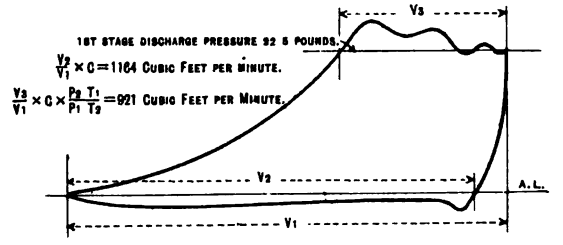
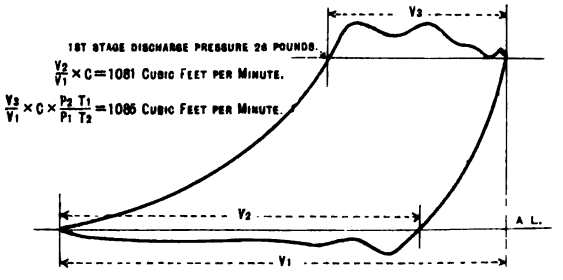
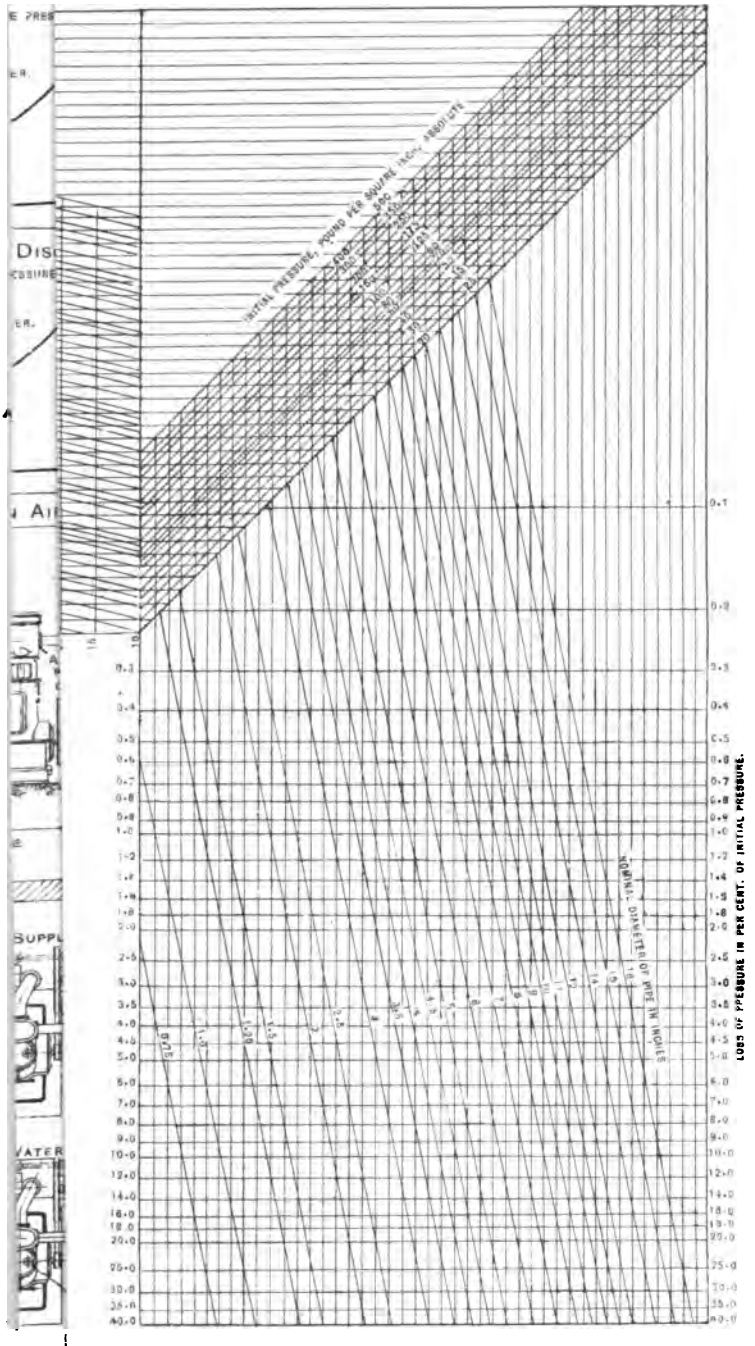

1ST STAGE DISCHARGE PRESSURE 92 5 POUNDS.
$\frac{V_2}{V_1} \times C = 1164$ CUBIC FEET PER MINUTE.
$\frac{V_3}{V_1} \times C \times \frac{P_2}{P_1} \frac{T_1}{T_2} = 921$ CUBIC FEET PER MINUTE.
V3
V2
V1
A. L.

FIG. 17.—SUCTION-VALVES AIRTIGHT.


1ST STAGE DISCHARGE PRESSURE 26 POUNDS.
$\frac{V_2}{V_1} \times C = 1081$ CUBIC FEET PER MINUTE.
$\frac{V_3}{V_1} \times C \times \frac{P_2}{P_1} \frac{T_1}{T_2} = 1085$ CUBIC FEET PER MINUTE.
V3
V2
V1
A. L.

OR AIR-COMPRESSOR.


INITIAL PRESSURE, POUND PER SQUARE INCH, ABSOLUTE
NOMINAL DIAMETER OF PIPE IN INCHES
LOSS OF PRESSURE IN PER CENT. OF INITIAL PRESSURE.

Transactions. 1915-1916.

*To illustrate Mr. John Gibson's Paper on "The Logic of Trams."*

FIG. 1.—SHOWING HOW WHEN POINTS AND CROSSINGS OF VARIOUS LENGTHS ARE USED, RAILS OF VARIOUS OTHER LENGTHS HAVE TO BE CUT AND USED FOR "SQUARING" AND "CLOSING."

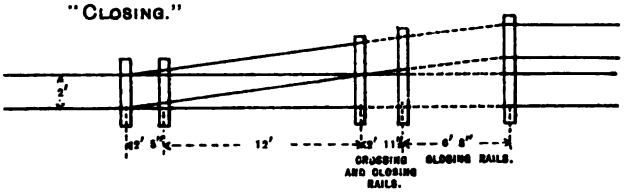



FIG. 2.—SHOWING HOW BY USING POINTS AND CROSSINGS OF STANDARD UNIT LENGTHS, NO RAIL-CUTTING IS NECESSARY.

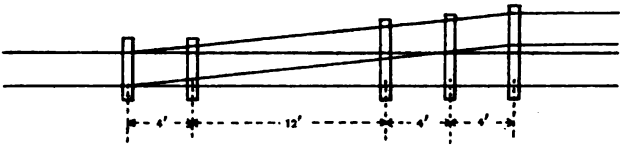



FIG. 3.—SHOWING THE RAIL-JOINTS ON CROSSGATE TOO FAR OUT-BYE, AND PATCHWORK OF SHORT RAILS OR WOOD USED.

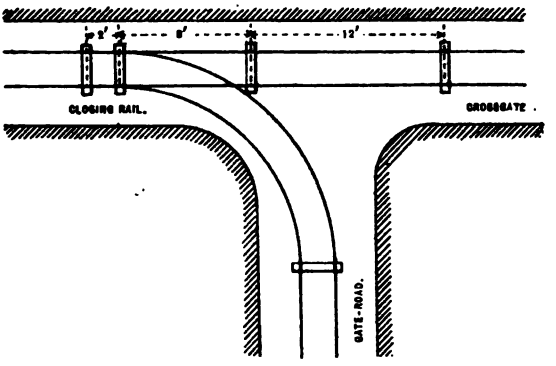
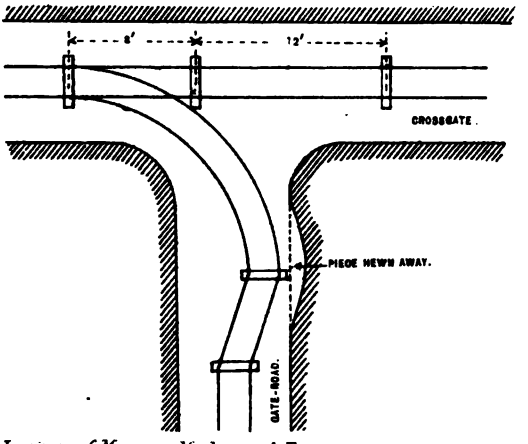



FIG. 4.—SHOWING THE RAIL-JOINTS ON CROSSGATE TOO FAR IN-BYE, WHICH NECESSITATES HEWING THE SIDE OF THE GATE-ROAD, AND AN AWKWARD TWIST ON THE RAILS OF THE GATE-ROAD.






And.w Reid & Comp.y L.td Newcastle upon Tyne

# THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS.

## GENERAL MEETING,

HELD AT THE QUEEN'S HOTEL, LEEDS, MARCH 21ST, 1916.

MR. THOMAS BEACH, VICE-PRESIDENT, IN THE CHAIR.

The minutes of the previous meeting were read and confirmed.

The following new members were elected:—

MEMBER—

Mr. ROBERT ETHERINGTON DOBINSON, 224, Sheffield Road, Barnsley.

ASSOCIATE MEMBER—

Mr. GEOFFREY EDWIN FOXWELL, 10, Violet Bank Road, Nether Edge, Sheffield.

Prof. PERCY GROOM read the following paper on "Pit-timber and its Preservation":—

# PIT-TIMBER AND ITS PRESERVATION.

By PERCY GROOM, M.A., D.Sc.,
PROFESSOR OF THE TECHNOLOGY OF WOODS AND FIBRES, IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, LONDON.

The wastage of timber in coal-mines that is caused by decay is very great; in fact, far greater in this country than is generally realized. Mr. E. W. Peters* estimates that of the whole wastage of timber in mines in the United States of America, 50 per cent. is due to decay and insects; of this 50 per cent., an overwhelming part is due to decay. The most efficient methods of decreasing this grave loss can be devised only by co-operation of the mining engineer and the scientific expert, and it is partly in the hope of procuring such collaboration that this paper is written. It contains, therefore, a *résumé* of our present knowledge of the decay of wood, and of the economic methods of checking this in mines; but, with a view to improving those methods, it also directs attention to the gaps in our knowledge, and the means by which these can be filled by future investigation.

The decay of wood in the overwhelming majority of cases is caused by wood-destroying fungi. The first step towards such decay is the infection of the wood, either by means of microscopic spores wafted through the air, or by the body (*mycelium*) of the fungus advancing from already infected material. In either case, fungal threads entering from the outside penetrate, grow within, and gradually permeate and destroy the wood.

Spores are produced in myriads by easily visible fructifications, which assume the forms of mushrooms, brackets, or sheets. Consequently one method of decreasing infection is to destroy these fructifications before they have produced or shed their spores. Such a collection and destruction of fructifications in coal-pits may sometimes be impracticable. On the other

* "The Preservation of Mine Timbers," by E. W. Peters, 1912, U.S.A. Forest Service, Bulletin No. 107.

hand, its efficiency may be underestimated; but the writer may point out that largely by this means the tinder fungus was practically exterminated in a large forest in Germany. Before this method is attempted, it is essential to know which fungi are doing serious damage in coal-pits; for this and other reasons it is necessary to identify critically the various fungi present.

Unfortunately, many kinds of fungi readily produce spores quite apart from such fructifications, the destruction of which might therefore be relatively futile. For this and other reasons, it is necessary to work out the life-histories of the fungi present in coal-pits; and we may then also learn how to prevent or decrease the production of spores.

Infection may take place by threads of the fungus advancing from an infected to a sound piece of wood. According to their mode of growth, wood-destroying fungi may be ranged in two groups. In one group the fungus, having established itself at a point in the wood, not only gradually grows within the wood, but also emits threads that emerge from the wood, grow rapidly over the surface, clothing this with growths, often white, and shaped like strings, sheets, or cushions.* These superficial growths in turn send threads into the wood, and thus feed upon it. Especially by means of these exposed string-like growths the fungus can pass from one piece of wood, through dirt or even brick walls, over stones, coal, or iron, and can infect a sound piece of wood several yards away. Fungi of this kind are very familiar in certain coal-mines, and are locally known as "cotton mould fungus." Mining engineers will at once call to mind a number of the ordinary operations in coal-mines that serve incidentally to transmit infection to sound wood from timber already attacked by fungi of this group.

In the other type of attack the fungus advances more slowly; for, having entered the wood, it eats its way steadily into the interior, and keeps at a certain distance from the outside. Wood infected by such fungi, especially when it is discoloured by various agencies in coal-mines, may show no appreciable external sign of its rotting condition, even when a shallow incision is made with a knife. This type of attack is certainly

* These must not be mistaken for fructifications, which often differ from them in colour, and usually display radiating gills (cp. mushroom) or crowded little pores, teeth, or pimples.

abundant in coal-mines (the writer has himself seen cases), and where it alone occurs the miner may readily, but wrongly, assume that his mine is free from decay. Here and there the fructifications of such fungi will betray the secret.

These considerations suggest that in a coal-pit where the swift-growing fungi of the first group are especially present, the durability of the timber may be considerably increased by rendering the surface of the wood resistant to infection; but where decay is largely due to the stealthy, slow-growing, internal fungi, decreased loss may often be more easily secured by destruction of the fructifications. The facts emphasize the necessity for enquiry into the life-histories of fungi in coal-mines.

The statement is frequently made with reference to certain coal-mines that there is little or no loss due to decay of wood. Facts just mentioned suffice to prove that such statements cannot be accepted without fuller investigation, even when pit-props break though apparently perfectly sound.

It may at once be admitted that in dry pits, or where the mine water is very rich in salts, there may be little or no decay; and it may also be admitted that props exposed to great pressures break while in a sound condition. Decay may thus play little or no economic part in certain deep coal-mines. Yet, if it be found that there are coal-mines free from decay, but showing conditions essentially similar to other pits in which decay is rife, then we arrive at the fundamentally important conclusion that the decay of wood in mines may be checked by the cheapest of all means, namely, sanitation of the simplest kind. It therefore becomes evident that we must acquire by investigation a thorough knowledge of the conditions prevailing in coal-mines, and this becomes doubly clear by a consideration of the effects of external conditions on the growth of wood-destroying fungi.

For the purpose of respiration, such fungi require a free supply of air, and particularly of oxygen, but they also demand an adequate supply of water. It is, therefore, clear that wood, either very dry or very wet, is generally safe from decay. When very dry, it has the air but not the moisture required; when water-logged, it lacks the requisite amount of air.* These

* Some woods decay relatively rapidly under water: the extent to which very wet wood in mines is destroyed by bacteria and the extent to which the latter are responsible for the production of marsh-gas ("firedamp") are unknown, and call for investigation.

facts, partly at least, account for the practice adopted in some countries of regularly drenching the wood with water, and for the circumstance that wood under an unceasing flow of water in coal-mines is generally durable.

As fungi will attack wood only when it contains more than a certain minimum and less than a certain maximum of water, we can understand why decay is often more pronounced along the return roads than along the intake, and why, in relatively dry mines, decay is worst in the wettest places, whereas in moist pits the reverse is the case.

Different kinds of fungi differ as regards the degree of dryness or wetness of the wood under which they can successfully thrive. One species, *Merulius lacrymans* (causing the worst form of dry-rot in buildings, and probably active in many coal-mines), when once established, can attack the driest wood. In respiration this fungus produces water in sufficient quantity to render the infected wood moist, wet, or sodden. It thus renders the wood liable to attack by other fungi that demand more water; indeed, in a relatively dry mine the extermination of *Merulius* alone might indirectly thus lead to the extirpation of some or all the other kinds of wood-destroying fungi present. This case again emphasizes the necessity for investigation into the conditions of existence of fungi living in coal-mines.

In order to protect wood against decay, it is sufficient to keep it absolutely dry or soaking wet.

Apart from the practical difficulty of keeping wood in pits wet, it must not be forgotten that wet wood is much weaker than dry wood (sometimes having only one-third the strength).

On the other hand, at present it is not economically practicable to prevent the ingress of air or moisture into pit-timber, for continuous impervious coatings are difficult to secure and maintain. Consequently, the protective effect of seasoning wood before use in coal-pits is determined by the dryness or wetness of the mine. If, for instance, pit-props be barked and then seasoned, their superficial dryness tends to protect them from decay so long as they remain dry; but wood is hygroscopic, so that in wet mines such props soon relapse into their former moist and vulnerable condition. On the other hand, if unseasoned props with intact bark be utilized in relatively dry mines, the intact bark acts as a shield against infection; but, as the

wood slowly and gradually dries, it shrinks, and in the bark there arise cracks, through which infectious spores gain entrance to the relatively moist wood within. These considerations supply an explanation of the contradictory results obtained by Mr. Peters in the United States of America, where barking the props was found to increase their durability in dry mines, but not in wet mines. In our own country the collection of statistics as to the relative humidity of the air in various coal-mines would give valuable indication as to the extent to which seasoning and barking, or the latter alone, would serve to preserve pit-props. The seasoning and barking would not only directly increase but also prolong the strength of props, and the significance of these facts may be especially great in the case of deep pits.

Yet dryness to some extent favours the production of fructifications, and consequently of their spores. Consequently such fructifications are, often at least, more developed along the intake roads than along the return; moreover, repeated drenching of wood tends to check the production of such fructifications.

The relatively high temperatures prevailing in coal-pits accelerate decay, since, so long as sufficient moisture is present, the activity and growth of the fungus are (within limits) proportional to the temperature. But each species of wood-destroying fungi grows only within certain ranges of temperature; for instance, *Merulius lacrymans* may be found growing in mines the temperatures of which lie below 80° Fahr., but not in deep coal-pits where the temperatures rise above this point. Of greater practical importance is the fact that exposure to high temperatures, especially associated with moisture, serves to kill fungi and their spores. Thus it is easy to sterilize pit-timber, and such sterilization often takes place during the process of injecting preservative liquids into wood. It must be remembered, however, that prolonged exposure of wood to temperatures above the boiling-point of water materially weakens the timber.

To digress for a moment from the question of decay induced by fungi, attention may be directed to the fact that the relatively high temperatures prevailing in coal-mines tend to promote the disintegration of wood by chemical agents. For instance, zinc chloride, a very efficient and economical wood-

preservative, can gravely attack timber when used in sufficient concentration at only moderately high temperatures. Iron sulphate, either applied as an antiseptic or casually occurring in mine water, undergoes decomposition, yielding sulphurous and sulphuric acids, the destructive action of which on wood is intensified by rise in temperature.

Wood-destroying fungi require appropriate raw food-material. Some of them can feed upon the sap-wood or heart-wood of many different kinds of timber; others can attack only hard-woods or only soft-woods, and sometimes only the sap-wood of these; still others may be greater specialists, and capable of attacking only one group (genus) of timbers, say, pine-woods. These facts provide a possible means of decreasing decay by selection of an appropriate immune kind of wood to replace decayed timber that has been removed; for instance, if the fungus occurring locally or generally in a pit exclusively attacks soft-woods, these (pine, spruce, larch) can be replaced by a hard-wood. Or again, if a pine pit-prop be rendered rotten by a fungus that cannot attack larch, it may be replaced by a larch prop; this will then not be infected from the pine coupling, which is also probably decaying from the same cause. But, before this economical method of sanitation can be applied, it is necessary to have full information as to the habits of the fungi concerned, and for this research is necessary.

The facts already stated serve to explain why it is that the durability of one and the same wood varies in different pits, and why the relative durability of different woods in different mines is not always the same. At Commentry, in France, the following were the estimates as to durability of pit-wood:—

| Pit-wood. | Months. |
|---|---|
| Oak ... ... ... ... ... ... ... ... | 50 |
| Beech ... ... ... ... ... ... ... ... | 24 |
| Pine, cherry, rowan, birch, and poplar ... ... ... | 18 |
| "False acacia" (*Robinia*) ... ... ... ... ... | 9 |
| Hornbeam and sycamore ... ... ... ... ... | 6 |

At the same pits the following was the order of durability noted in certain observations—the list beginning with the most and concluding with the least durable:—Oak, Scots (Baltic) pine, alder, ash, cluster pine, "false acacia," willow, sycamore, elm, aspen, cherry, birch, hornbeam, beech, and poplar (other than aspen). The different position of beech in the two

lists is noticeable. In this country Scots (Baltic) pine, cluster pine (from France), larch, oak, with some small quantity of ash and birch, appear to be the woods chiefly used: it is also stated that in some pits Norway spruce is employed. Of these timbers, larch and oak are the most durable at ordinary levels. As to the comparative durability of these woods in pits in this country, the writer has no statistics available.

It is assumed that the different kinds of wood vary in durability in accordance with the amount of fungus-repelling or antiseptic material that they contain or produce when attacked. And this leads to the fact that artificial durability may be given to timbers by the application of antiseptics or fungicides. All solutions may act antiseptically if sufficiently concentrated: for instance, sugar, though a food admirably suited to promote the growth of fungi, when concentrated arrests the growth of these.

*Common salt* (sodium chloride) in concentrated solution is an antiseptic, and when naturally abundant in coal-mines undoubtedly protects the wood. But its hygroscopic qualities and relative weakness of action seriously detract from the value of common salt as an artificial antiseptic.

*Ferrous sulphate* is very uneven in its effects, sometimes considerably prolonging the life of timber, at other times being associated with rapid decay. Undergoing oxidation, it deposits oxide of iron on and in the wood, and thus tends to check the ingress of water; but it produces sulphurous and sulphuric acids, which may on the one hand attack the wood directly, and, on the other hand, successively act as an antiseptic and a food-material in relation to fungi. These facts suggest as worthy of trial the whitewashing of bare wood in pits where ferrous sulphate is abundant in mine water. The lime present will neutralize the acids, and tend to form an impervious sheet outside the wood.

*Corrosive sublimate* is not to be recommended, as being extremely poisonous. It is dangerous to handle; moreover, it is easily washed out, and is volatile.

*Copper sulphate* as a fungicide in wood gives remarkably variable results. Sometimes it is very efficient, but in other cases it causes very rapid disintegration of the wood (possibly because of free acid). In the presence of ferrous sulphate its destructive action is especially marked. Hence, copper sul-

phate cannot be recommended for use, and must be especially avoided when mine water contains ferrous sulphate.

If initial cheapness and prolonged efficiency be taken into consideration, *zinc chloride* is the best inorganic fungicide for use in connexion with the preservation of wood. As a superficial wash, its value is diminished greatly where the wood is exposed to rain. In efficiency it is surpassed by several other costly salts, such as magnesium fluosilicate.

*Creosote* and its derivatives constitute the most satisfactory preservatives of wood, for creosote is a more powerful fungicide than zinc chloride, and is not washed out. Moreover, if the wood be seasoned, creosote retards the absorption of water, and thus indirectly contributes to the strength of timber in moist places. Among the cheaper derivatives of creosote may be mentioned cresol calcium, which is being tested on railway sleepers. The most efficient derivatives, however, are the dinitro-phenates and cresates of sodium and potassium, and one or more of these, with admixtures of other substances, may become of commercial importance in this connexion.

But, as is shown by the succeeding table summarizing Fayol's observations, prolonged investigations and trials are required to show the relative efficiency of various treatments in different coal-mines, as in some cases simple measures, or cheaper or more dilute antiseptics, are as efficient as more costly antiseptic treatment.

Moreover, the measures to be adopted vary with the length of service required of the timber: for instance, it is superfluous to protect against decay a piece of wood which is required to serve only for a very short time (say, two months), or which breaks under pressure long before it could be mechanically weakened by decay.

The series of treatments considered in the succeeding numbered paragraphs represent for the most part a progressive rise in cost of treatment and in enhanced durability.

(1) Seasoning and barking of wood have effects the limited efficiency of which has already been discussed. It may here be added that Peters found that in dry, well-ventilated mines seasoning sometimes increased the durability of the wood by 25 per cent.

(2) Carbonizing or braizing the outside of timber serves to

provide an aseptic or antiseptic and at least temporarily dry surface, which, however, is liable to be subsequently broken. Fayol's table dealing with the Commentry mines shows that this treatment is often ineffective, though sometimes efficacious.

(3) Painting the surface of the wood with various antiseptic liquids yields limited and uncertain results, as it is difficult to secure and maintain an absolutely continuous antiseptic coating. Nevertheless, where the antiseptic could not be washed off, and the substance used was creosote, Peters showed that seasoned loblolly pine had an increased durability of from 50 to 100 per cent. Hence this treatment is of value where the amount of wood requiring preservative is small, and where the period of required service is moderately short (say, 2 to 4 years).

COMPARATIVE DURABILITY OF PIT-PROPS IN COAL-MINES AT COMMENTRY (COMPARED WITH UNTREATED WOOD, WHICH IS RECKONED AS 1).

| Nature of the wood. | Immersed in, or treatment. | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mine water. | Superficially braised. | Tar. | Creosote. | Sulphate of copper. | Sulphate of iron. | Chloride of zinc. |
| Oak, common .. | 10·4 | 1 | 14·4 | 3·6 | 38·4 | 28·8 | 14·4 |
| Cluster pine .. | 1 | 1 | { 50 / 2·33 } | 40 | 5·33 | 2·66 | 8 |
| Alder .. .. | 1 | 1 | 2·11 | 40 | 4 | 10 | 40 |
| Beech .. .. | 1 | 1·37 | 6 | 1·75 | 50 | 7·5 | 50 |
| False acacia (*Robinia*) .. | 1·2 | 7·22 | 5·33 | 2·2 | 8 | 26·6 | 40 |
| Hornbeam .. | 3 | 2·5 | 7 | 15 | — | 12 | 50 |
| Sycamore .. | 2·5 | 3 | 6 | 12 | 7·5 | — | — |
| Cherry .. .. | 1·66 | — | 3·16 | — | 2·5 | 1·83 | — |
| Aspen .. .. | 1 | — | 2·5 | — | 2·5 | 8 | — |
| Birch .. .. | 1 | — | — | — | 2·66 | 13·33 | 50 |
| Poplar (not aspen) .. | 1 | — | 2·2 | — | 11·33 | 2·61 | — |
| *Sorbus* (rowan, etc. .. .. | — | — | 1 | — | — | 50 | 28 |
| Range .. | 10·4–1 | 7·22–1 | (50) 14·4–1 | 40–1·75 | 50–2·5 | 50–1·83 | 50–8 |
| Average .. | 2·25 | 2·44 | (9·06) 4·73 | 16·36 | 13·22 | 14·85 | 35·05 |

Duration of immersion —12 hours in the case of the salts of iron, copper, and zinc; 30 minutes in the case of tar and creosote.

The strengths of the solutions were respectively: iron sulphate, 5 per cent; copper sulphate, 10 per cent; zinc chloride, 10 per cent; the creosote and tar were heated to 140° Cent.

(4) Immersion of the wood in a warm or hot tank of antiseptic is more efficient than the mere painting of the surface with the same preservative, for a more continuous antiseptic coating and deeper penetration are obtained. The accompany-

ing table giving Fayol's results at Commentry demonstrate the efficiency of the method in the cases of various timbers and antiseptics. The table must not, however, be taken as an accurate indication of the comparative efficiency of the various antiseptics. Some of Peters's observations in America seem to illustrate the superiority of tank treatment over mere brush work on the surface; for Peters noted that tank treatment with the relatively weak antiseptic solution, common salt and magnesium chloride (15 per cent.), gave greater durability than brush treatment with the potent fungicide creosote. Where the amounts of timber to be preserved are not great, tank-treatment is the simplest and most economical method that can be applied, if the period of service required of the wood is considerable.

It must be noted, however, that too prolonged treatment in a bath at a temperature exceeding the boiling-point of water weakens timber, so that pit-props are then apt to fail by rupture.

(5) Thorough impregnation of the wood by means of pressures exceeding one atmosphere constitutes the method of applying antiseptics that is most efficient, and, where large quantities of timber are concerned, most economical. This method is well illustrated by the familiar process of creosoting by pneumatic pressure in closed chambers. Of this normal process there are various modifications, some being designed to ensure thorough penetration of the wood, succeeded by an expulsion of the excess of creosote. Possibly one of these modifications will be found the most suitable in connexion with coal-mines. So far as decay is concerned, such thorough creosoting involves an increase in durability from perhaps a month or two to an indefinite number of years (creosoted wooden fences still perfectly sound after forty years of use, and railway sleepers free from decay after more than twenty years of use in one form or another, are known).

The main conclusions in this paper may be summarized as follows:—

By means of research into the identities, life-histories, and conditions of growth of fungi causing the destruction of wood in coal-mines, we may hope to initiate a new policy, that of *militant sanitation*, involving the suppression of decay by the most economical of all methods.

In less favourable cases, by an analysis of the conditions prevailing in coal-mines and by a consideration of the required durability of the wood in various cases, we can improve upon the current methods of mere *defence* by selecting the cheapest and most suitable method known or discovered by future research.

The efficiency of the methods and the resultant economic profit will depend upon the amount of research and the extent of the co-operation between scientific and mining experts.

Such increased preservation of timber involves a saving not merely from the point of view of the colliery proprietor, but also in the amount of timber imported into this country; for most of our pit-props come from the Baltic region and some from France. With the continual rise in the price of soft-wood timber, this saving will increase with years. W. F. Sherfesee,* assuming that in the United States of America the average life of an untreated pit-prop is three years, and of an antiseptically treated pit-prop thirteen years, and that 40 per cent. of mine timber could be profitably treated antiseptically, concludes that the annual saving to the United States of America involved by such treatment would be 51,700,000 cubic feet of timber. Without relying too greatly on Sherfesee's estimates, and still less without applying them to this country, we may hold that they sufficiently indicate the immensity of the saving that may be possible in this country by improved sanitation and appropriate treatment of wood in mines.

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The CHAIRMAN (Mr. Thomas Beach) said that doubtless a great deal might be done to preserve timber used underground, but in the majority of the pits in their district the timber was broken before it had a chance to decay. In some of the shallower mines, however, where timber might stand for years, very great economies could be brought about by some method of dealing with the fungi in the manner indicated in the paper.

Prof. W. G. FEARNSIDES (Sheffield University) said that in a number of the shallower mines between Leeds and Sheffield,

* "Wood Preservation in the United States," by W. F. Sherfesee, 1912, U.S.A. Forest Service, Bulletin No. 78.

especially in those where gannister and refractory fireclay was being won along with the coal, one could not help noticing the luxuriance of the fungoid growths. The speaker, when he visited pits, went as a geologist, but having once had to learn something about the parasitic habits of the mushroom class, he had felt bound to tell the colliery officials that their timber could not continue to nourish such growths without a corresponding loss of strength. He believed it was because an infected prop had been brought to daylight for his inspection, and was afterwards sent on to Prof. Groom, that the latter was now at Leeds discussing with them the general question of pit-timber preservation.

From what he had himself seen underground, he quite agreed that probably the most hopeful way of dealing with the fungi was to clear away their fructifications before the spores ripened. Infection by spores was certainly important underground, and with new timber in a new place one could generally notice that the onset of fungi was from the windward side. Once started, the growths spread vegetatively to the lee, and usually the large "cushions" and filmy festoons which are the outward manifestations of the fungi at the phase of their maximum destructiveness are always most abundant in those damp dank places where the ventilation of the mine is "slack." As to the amount of the damage done by fungi in the coalfield, the speaker could not do more than guess. It seemed to him that, since the total weights borne by the timber in shallow mines are so much less than the weights carried in deep mines, mechanical breakages ought, therefore, to be less in shallow than in deep mines. He had always heard that timber charges per ton of material wrought in the gannister mines were higher than those in any other class of mine in the coalfield, and were considerably higher than the average of timber charges over the coalfield generally. He felt sure that in gannister mines a great deal of timber destruction was accomplished by fungi, and he thought that anything which would prevent the onset of fungi in these mines would save a very considerable quantity of timber and would be well worth while.

The whole question was certainly not an easy one, and there were many conditions beyond those which met the eye. He would like to suggest that acidity of pit-water was a condition

which favoured the rapid spread of fungi, and he thought that the composition of the water, as well as the temperature, humidity, and composition of the air, should be subjects for enquiries collateral with the investigation of pit fungi from the botanical point of view.

Mr. W. D. LLOYD (Altofts) said that (so far as the deeper pits were concerned) he thought that the paper conveyed rather an erroneous idea of the amount of saving that was likely to be obtained in the timber bill. In a great many mines in the district, fully 75, and in some cases at least 90 per cent. of the timber was used on the coal-face, and was set at most only three or four times before it was broken up, so that as its life was but a few weeks or months, there was no chance of decay setting in before the timber was rendered useless. He had had experience in the Midlands, in Lancashire, and in Yorkshire, and he could only recall one case in which timbers had to be renewed owing to decay was there, but, at the same time, the proof as to harm caused by the decay depended on whether the timber had to be renewed or not. The case that he had mentioned was rather curious in some ways: a large number of unpeeled larch bars were set in a return airway in a saturated atmosphere of about 58 degrees, and after being in for two years they all started to fail from decay; but the remarkable point was that the Norway pine props, on which the bars were supported, were not attacked in any way.

From the figures given by Prof. Groom with respect to American mines, and from what had been stated concerning shallow mines, it would appear that a saving might really be effected in those pits, but not in the deeper mines. He imagined that there could not be a better condition for the preservation of timber than in the return airways of some of the Yorkshire mines, at a depth of 500 to 800 yards, where the temperature was from 70 to 80° Fahr., with a difference of 4 or 5 degrees between the dry and wet bulbs. Under such conditions there was, so far as one knew, no tendency whatever for decay to set in. He had seen within the last year or two oak pit-props that had been underground for over 50 years, and, when these were cut into sections, there appeared to be no decay in them. The props were at a depth of about 230 yards, and had been shut up in a more or

less stagnant atmosphere for the greater part of that time in a place that was fairly moist.

Mr JOHN GILL (Normanton) said that the colliery with which he was connected, working a seam at a depth of about 300 yards, was occasionally wet and occasionally dry. The timber was affected by fungi both in the returns and in the intakes, but in quite a different manner. The fungi attacked the bars in the returns, and the foot of the props in the intakes, and he would like to know the reason for this difference. The mine was wet and fairly warm, and a great number of shots were fired in it. The timber had to be changed frequently; in fact, at the present time iron was being substituted for wood in the intake on account of the props being attacked from the bottom.

Mr. R. NADIN (Brierley) said that at a shallow pit 218 yards deep with which he was connected they were troubled with fungi, particularly where the ventilation was slack. In some districts, even the props in the bords were attacked. The seam was worked on the bord-and-pillar system, the bords being driven up a distance of 100 yards, and by the time the pillars were worked back the timber supporting the bords was in some cases attacked by the fungi. Prof. Fearnsides had visited the colliery recently, and had remarked on the condition of this timber. Since then he (Mr. Nadin) had had the large timber painted with a mixture. He could not yet judge whether this treatment was beneficial, but he hoped that it would save money.

The CHAIRMAN said that when timber decayed it generally did so between wind and water. If they burned the foot of a stake, or coated it with tar or creosote, it would last much longer. He had one case in mind where the whole place was covered with cushions of fungi, but there was very little weight on the timber. It would be interesting to know whether Mr. Nadin's experiment of coating the timber was successful.

On the motion of the CHAIRMAN (Mr. Thomas Beech), seconded by Mr. W. M. WATERHOUSE, a very cordial vote of thanks was accorded to Prof. Groom for bringing this important subject before the members. Their pleasure had been greatly enhanced by the brilliant *vive-voce* address to which they had listened.

## DISCUSSION OF MR. EDWARD LLOYD'S "NOTES ON THE USES AND MARKETS OF BYE-PRODUCTS OBTAINED FROM COKE-OVENS."*

Prof. L. T. O'SHEA (Sheffield University) wrote that the excellent *résumé* of the latent powers for development in the coking industry was worthy of serious and careful consideration by the industry. The opportunity appeared to have arrived when it could establish itself as a national undertaking ready to supply the needs of the industries which relied on the various products of coal-distillation for their raw products.

In considering how they were to set to work to achieve this end, it was as well to take into consideration Mr. Lloyd's remarks on the manner in which Germany had established her "cast-iron monopoly of the coal-tar industry." Not only had she used every financial and commercial artifice to keep a tight hold on the industry, but this had been made possible by the intimate relations which existed between industrial expansion and scientific research. The German coal-tar and subsidiary industries had not been built up by haphazard methods dependent on fortuitous discoveries, but by patient and carefully thought-out investigations placed in the hands of highly-trained experts. Mr. Lloyd had hinted at this when he referred to the time required to develop successfully the processes involved, and to the fact that we had yet to organize and train a competent staff to conduct research.

This appeared to the writer to mean that the industry at present was not properly controlled, and coming as it did from a man of Mr. Lloyd's experience and attainments that statement required serious consideration. The industry was a chemical industry dependent on the laboratory for control, and the writer would ask: Is the man who learnt his chemistry in evening classes and the coke-works laboratory sufficiently trained to meet these requirements?

Mr. Lloyd had asserted that it was for the coal-industry to see that a plentiful supply of raw material was forthcoming, and herein lay scope for investigation. The 5,000,000 tons of coal carbonized in beehive ovens were said to be necessary because the steel manufacturer found that retort cokes did not

* *Trans. Inst. M. E.*, 1916, vol. l., page 509.

satisfy his conditions of working. Fifty years ago this was demonstrated by Sir Lowthian Bell to be the same for blast-furnace work, but it was not so to-day. Was it not for us to produce a coke in the retort-oven which would fulfil the steel manufacturers' requirements, and would not then these 5,000,000 tons be coked in the retort-oven and the £1,750,000 profit mentioned by Mr. Lloyd realized?

Again, about 20 per cent. of non-coking coal was to-day left in the pit. Could this coal be distilled and made to yield serviceable tars? If so, the supply of crude products could be increased. But this problem entailed investigation into the uses to which the non-volatile residues could be put, as well as the character of the tars produced. If a profitable market could be found for the residue, and valuable tars could be produced, why should not this coal be distilled? Herein lay possibilities of expansion.

Another subject for the careful consideration of the coal distiller was the low-temperature distillation of coal. The possibilities in this industry seemed to the writer to be two: (1) the supply of an easily ignitable but smokeless fuel to replace coal for domestic use, and (2) the production of suitable oils for motor-spirit, burning, and lubricating purposes. Some investigations had already been made in this field, but they were far from complete.

There were other problems which would suggest themselves, but there was one that appeared to the writer to be of supreme importance, and could be approached without much hesitation, namely, that of waste. Given our present methods of working, were we obtaining the best results? Had we attained the highest limits of recovery of the various products that we set out to recover, and were we making full use of every one?

The first was a question of control. It was a chemical or physical problem controlled by laws which must be fulfilled, and only by daily control from the laboratory was it possible to know whether the highest limits were reached, and, if not, where the defect was.

In the second part of the question one naturally turned to the uses to which the residual gases were put, and doubtless here one was bound to confess that waste was at present going on.

There were various well-known uses to which this gas

could be put, among which were (1) the production of steam or electricity for use at the colliery; (2) the supply of illuminating-gas to rural districts or neighbouring gas-works; (3) the supply of gaseous fuel to local consumers; and (4) the supply of electricity for power purposes at a cheap rate. These problems had received considerable attention, and (1) and (2) had been applied successfully in a few instances. The success which had attended Mr. G. Blake Walker's enterprise at Wharncliffe Silkstone Colliery was worthy of serious consideration.

The supply of fuel to local consumers was a fascinating problem for collieries favourably situated. It should be easy of solution if the consumer was satisfied that the fuel would meet his requirements and the producer that it was within his power to meet them. The problem for him was not merely a question of mains and statutory powers, but also of uniformity of composition and regularity of supply. Let the producer show by actual figures that he could meet the demand of the consumer, and no sledge-hammer procedure would be required to make this source of fuel available.

The last method had received consideration from time to time, and suggestions had been made for grouping collieries together for the supply of gas to a central electric supply station. It was unnecessary to enlarge on the advantages of cheap electricity for power purposes. What the electrician wanted was cheap fuel. Could the producer supply it in the form of gas?

In all these problems three factors must be considered—(1) the theoretical soundness of the proposition, (2) the possibility of practical solution, and (3) the probabilities of financial success.

The first factor lay within the province of the scientific expert, and unless that was established it was useless to go on to the second. The second was the province of the highly-trained man, whose experience enabled him to devise plant and machinery for the process. When this was accomplished, the third was assured, provided that a suitable market existed.

It was realized that the close co-operation of scientific and practical experience was necessary in dealing with problems of industrial research. An Advisory Board for Industrial and Scientific Research had been formed, which was calling to its assistance experts in the various industries. A Mining Com-

mittee had been formed on which The Institution of Mining Engineers has been asked to suggest the representatives for coal-mining, whilst the Institution had appointed its own committee to suggest subjects for research. Further, the British Association for the Advancement of Science had appointed a committee to enquire into the subject of fuel economy. This committee consisted of representatives of the most important national industries that produced and used fuel, together with the leading scientific authorities. All this seemed to indicate that these problems would receive thorough and careful investigation.

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## DISCUSSION OF PROF. WILLIAM GEORGE FEARNSIDES'S PAPER ON "SOME EFFECTS OF EARTH-MOVEMENT ON THE COAL-MEASURES OF THE SHEFFIELD DISTRICT (SOUTH YORKSHIRE AND THE NEIGHBOURING PARTS OF WEST YORKSHIRE, DERBYSHIRE, AND NOTTINGHAMSHIRE)."*

Mr. Alexander Faulds (Vancouver, B.C.) wrote that many wash-outs were to be found in the Pyotshaw and Main Coal Seams, and in some cases in the Slaty Band Ironstone Seams of Lanarkshire. These wash-outs were due to old river-beds, which thickened the coals (equivalent in quantity to the area of the wash-out) at the edges of the "wants," as they were called in Scotland. Another characteristic of the Pyotshaw and Main Coal Seams was the thickening of the strata between these seams from a mere parting to several fathoms within a distance of several hundred fathoms.

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* *Trans. Inst. M. E.*, 1915, vol. l., page 573; discussion, vol. l., pages 109 and 608.

# THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,
HELD IN THE ROOMS OF THE SOCIETY, QUEEN'S CHAMBERS,
5, JOHN DALTON STREET, MANCHESTER,
MARCH 14TH, 1916.

MR. LEONARD R. FLETCHER, PRESIDENT, IN THE CHAIR.

## DEATH OF MR. ROBERT WINSTANLEY AND LIEUTENANT LAITHEWAITE.

The PRESIDENT (Mr. Leonard R. Fletcher) announced the death of Mr. Robert Winstanley, who was elected a member in 1876 and had filled the position of President during the years 1895-1896. Mr. Winstanley had contributed some valuable papers to the *Transactions*, and the Society had suffered a great loss by his death.

Mr. JOHN GERRARD proposed that a letter of condolence should be sent to the family of the deceased member, and this was agreed to.

The PRESIDENT also referred to the death of Lieut. Laithewaite, who had been killed in action in France. They were all proud that so many of their members had been able to serve their King and country in the present war, and the least that they could do was to honour the memory of the deceased officer by forwarding a letter of sympathy to his parents.

Mr. EDGAR CHARLES EVANS read the following paper on "Carbon Dioxide as an Agent in the Extinction of Mine Fires, with Special Reference to its Use at the Senghenydd Colliery":—

# CARBON DIOXIDE AS AN AGENT IN EXTINGUISHING MINE FIRES, WITH SPECIAL REFERENCE TO ITS APPLICATION AT THE SENGHENYDD COLLIERY.

By EDGAR C. EVANS, B.Sc., F.I.C.

*Introduction.*—The subject of mine fires is one that has always attracted the attention of mining engineers in this and other countries, and yet, despite the researches of mining technologists, chemists, and microscopists, our knowledge of the phenomena of mine fires is in many respects imperfect. This is especially the case—from a scientific point of view—when the action of inert gas on mine fires is considered. At first sight, the extinction of a mine fire by the action of some such gas as carbon dioxide would appear to be quite a simple and practicable operation. This gas has a pronounced extinctive action on flame, it is the medium used in many most effective chemical extinguishers, and it has been utilized with marked success in extinguishing fires in the holds of coal-ships, under conditions of space, temperature, and mass of burning substance directly comparable with those existing in mine fires. Further, a well-known method of dealing with mine fires is to seal them up and allow the gases generated automatically by the combustion to act as the extinctive agent. It seems, therefore, only reasonable to suppose that carbon dioxide injected into such a walled-off area would accumulate to such an extent as to produce an atmosphere absolutely extinctive to combustion. The general consensus of opinion among mining engineers, however, is against the adoption of carbon dioxide, and when the available records of its use in mining work are consulted, it is seen that this opinion is thoroughly justified by the number of failures that have been recorded in cases where it has been tried.

From a consideration of the theoretical aspects only of the question, it becomes evident that the matter is not so simple as it appears to be at first sight. Prof. Clowes* and Dr. Haldane†

* *The Detection and Measurement of Inflammable Gas and Vapour in the Air* by Frank Clowes and Boverton Redwood, page 158.

† *Trans. Inst. M. E.*, 1894, vol. viii., page 549.

have shown that the addition of 14 to 16 per cent. of carbon dioxide to atmospheric air—a quantity sufficient to reduce the oxygen content to between 17·5 and 18 per cent.—creates an atmosphere extinctive to an oil-flame, an alcohol-flame, and a candle-flame. In order to extinguish a hydrogen-flame, however, it is necessary to add 58 per cent. of carbon dioxide to atmospheric air—involving a reduction of the oxygen to 8·8 per cent.—whilst it has been shown by Dr. Harger* that an acetylene-flame is not extinguished until the oxygen is reduced to 9·5 per cent.

When the question of oxidation of coal (apart from combustion) is considered, the matter becomes still more complicated. It has been shown by Messrs. Haldane and Meachem,† and later by Mr. T. F. Winmill‡ that coal continues to absorb oxygen from atmospheres containing percentages of that gas far below the limits required for combustion. The probability is that such absorption would continue—with consequent evolution of heat—as long as any oxygen remained in the atmosphere surrounding the coal. When to these considerations are added the influence of temperature, the effect of the composition of the coal, the effects of such impurities as moisture and sulphur in its different forms, the effect of size of the coal-particles, etc., it is evident that, even from a purely laboratory point of view, the problem is complex; whilst, when the venue of operations is transferred to the mine, with its entirely new set of conditions, with leakage, changes of ventilation, fluctuations of pressure and temperature, factors continually varying both in extent and in their mode of influence, then inconsistencies and discrepancies between theory and practice are certain to be inevitable.

*The Fire at Senghenydd Colliery.*—The fire at the Senghenydd Colliery occurred as the result of the disastrous explosion of October 14th, 1913. This explosion was confined to the west side of the colliery; and as a result the timbers in the main intake on this side were set on fire; but these were soon buried

* *Coal, and the Prevention of Explosions and Fires in Mines*, page 27.

† *Trans. Inst. M. E.*, 1898, vol. xvi., page 457.

‡ *Ibid.*, 1913, vol. xlvi., page 573.

beneath falls, and the fire continued under them. Attempts were made to extinguish it with water, with the aid of chemical extinguishers, and by digging it out; but these had to be abandoned, and ultimately the fire-zone was sealed off by "bashings" (stoppings) erected at *A*, *B*, *C*, and *D*, as shown on the plan (Fig. 5, Plate IV.). The stopping at *A* in the main intake was constructed entirely of sand-bags, and was 34 feet high; the stopping at *B*, called the "Pretoria bashing," was 35 feet high, and was built of sand-bags and faced with concrete; while the stopping at *C* (called the "Klondyke bashing"), closing the exit of the Klondyke stables into the main return, was built of concrete. The whole of the length of roadway at *D* was filled with rubbish and the mouth sealed with concrete.

Previous to and during the erection of these stoppings, analyses of samples of air were taken on the in-bye side of the fire, and these gave the results recorded in the Appendix under the dates October 21st and 25th and November 10th, 1913.

It will be noted that, with the exception of the sample of November 10th (which contained a considerable quantity of air, and was evidently not representative), a considerable amount of carbon monoxide was present, showing considerable combustion, whilst the high percentage of hydrogen is evidence of high temperature.

After the erection of these bashings, temperature measurements were taken hourly at the air-bridge shown on the plan (Fig. 4, Plate IV.), and in one of several cavities near the roof of the Klondyke bashing.

The air-bridge (which is frequently mentioned in the subsequent remarks) consisted of a disused boiler-shell. Holes had been bored in this, and several thousand bags of sand had been poured into it whilst water was pumped continuously into it, day and night, in the hope that it would penetrate into the fire area. It will be noted from Fig. 7 (Plate V.) that it was in direct communication with the fire area, and, therefore, analyses of samples of gas taken through holes in the out-bye side of the boiler-shell gave an excellent indication of what was taking place in the fire area. After the installation of the carbon-dioxide plant, a water-gauge was also placed here, and the readings of this instrument gave some most valuable results, which will be referred to later.

The cavities mentioned in the Klondyke return were of a somewhat extensive character, and for a considerable period they emitted large volumes of steam and blackdamp from the fire. It proved a task of considerable difficulty to keep these airtight. The roof and walls were extremely friable, and no sooner was one cavity filled than another appeared in a fresh place. Ultimately it was found necessary to arch the roadway for some considerable distance on both sides of the entrance to the Klondyke stables. The "breathing action" so often mentioned in the case of mine fires was especially noticeable in the gases emitted from these cavities. A thermometer inserted in one of these cavities gave a steady rise and fall of about 6° Fahr. in two minutes.

It was hoped that with the erection of the "bashings" the fire would become gradually extinguished, but the temperature measurements gave no indication that this result was being achieved, and it soon became evident that further measures were necessary. When the bashings were first put up, the air travelled from the downcast along the Main West Level, and then up the No. 1 North (Fig. 5, Plate IV.). The air-pressure against the out-bye bashing was, however, considerable, and, in order to relieve it as far as possible, regulators were placed in the crosscut and a considerable quantity short-circuited in this way, whilst three walls were erected running over half the distance across the roadway between the downcast and the out-bye bashing. The pressure of air, however, against the out-bye bashing was still excessive, producing considerable leakage, and therefore the ventilation was changed to that shown in Fig. 4 (Plate IV.), the air travelling along the Main East Level and down the No. 1 North. This produced an immediate improvement and the temperature of the thermometer in the air-bridge dropped about 6° Fahr. in a few hours. This improvement, however, did not continue. A new condition of equilibrium set in, and analyses of samples taken on November 25th and December 6th showed that combustion was still proceeding.

The decrease in the oxygen and the increase in the carbon dioxide shows that leakage had considerably diminished, whilst the reduction in the percentage of carbon monoxide points to a decrease in the combustion. Progress, however, was so slow that it was decided to try the effect of inert gas.

*Installation of Carbon-dioxide Plant at Senghenydd Colliery.* (Figs. 1, 2, and 3, Plate IV.).—After consideration of the various methods suggested for the production of inert gas in dealing with mine fires, it was decided to generate carbon dioxide and inject it on to the fire. Carbon dioxide was chosen in preference to exhaust gases for the following reasons:—(1) It has a greater specific heat. (2) The greater density of carbon dioxide would be of advantage, not so much from the fact of its settling near the floor of the roadway in the fire area, as from the point of view of counteracting leakage. If the assumption is made that the leakage of air inwards through the strata, and the leakage of blackdamp outwards, takes place according to Graham's Law of diffusion of gases, then it would be only reasonable to suppose that the oxygen and nitrogen and other light gases would escape from the fire area faster than the carbon dioxide. It was therefore anticipated that there would be a continuous gradual increase in the percentage of carbon dioxide. This anticipation, however, was not realized, but it was one of the reasons which led to the use of carbon dioxide alone rather than exhaust gases.

Pure carbon dioxide has several times been used in mining operations, and several instances are recorded in the *Transactions* of the use of liquid carbon dioxide. It was, however, realized that the operation at Senghenydd would be one extending over several weeks, and it was of the utmost importance that the discharge of the gas should be continuous. It was feared that difficulties would arise in the regular discharge of the gas from cylinders of liquid carbon dioxide, especially when this discharge would have to be extended over a fairly prolonged period, and therefore it was decided to adopt a chemical method of preparation.

It was estimated that there was an air-space of 130,000 cubic feet inside the various bashings, and provided that these were reasonably airtight, it was hoped, with an hourly discharge of about 400 cubic feet, that within three or four weeks the percentage of carbon dioxide in the fire area would rise to such an extent as to extinguish completely all combustion. This expectation seemed all the more reasonable when it was seen that the air in the fire zone (on the in-bye side of the fire) showed a percentage of oxygen amounting only to about 6·0 or 6·5.

It was decided, therefore, to instal a small plant of the type used in mineral-water factories and capable of producing from 400 to 1,000 cubic feet an hour. The particular type chosen was the "No. 4 $CO_2$ Generator," made by the Riley Manufacturing Company, Limited, of South Lambeth, the essential details of which are shown in Fig. 1 (Plate IV.).

In order to ensure an uninterrupted supply of gas, two of these generators were installed at Senghenydd. They were connected with a small air-pump capable of supplying from 300 to 1,000 cubic feet an hour.

The whole plant was erected beneath the staging of an old hauling-engine in the main intake, the necessary shafting and pulleys being fitted to the platform above. The plant worked from beginning to end without a hitch, and proved thoroughly satisfactory for the purpose for which it was required. Bicarbonate of soda was used instead of limestone for the generation of carbon dioxide. The former substance possesses considerable advantages over the latter. In the first place, the evolution of gas is much more regular and more easily controlled, while, bulk for bulk, the amount of carbon dioxide evolved is much greater with bicarbonate of soda than with limestone. The effluent also would be a clear solution, and could be dealt with easily, a condition that was of the utmost importance in working under mine conditions. Moreover, owing to the constancy of composition of the bicarbonate of soda, the regulation of the acid supply could be done quite easily by an unskilled man. A further consideration lay in the fact that a grinding mill would have to be installed if limestone were used. The drawback to the use of bicarbonate of soda lay in the fact that it was far more expensive than limestone, but it was not anticipated that the plant would be working for more than three or four weeks, and the advantages in other respects were so obvious that it was hoped that these would counterbalance the increased cost. It will be seen, however, that these expectations were not realized, and the process proved considerably more costly than had been anticipated.

A channel was cut from the generator to the sump to deal with the effluent, while a plentiful supply of water was available to clear this if occasion should arise. For the first few days the effluent was passed through a lime-tank, so as to ensure its

perfect freedom from acid; but it was found to be so easy a matter to adjust the acid supply that this was afterwards dispensed with; in order to ensure freedom from acidity, the effluent was always kept very slightly alkaline, the men in charge of the generators making the necessary tests with litmus paper.

*Analytical Control of Operations.*—The amount of carbon dioxide that was proposed to be pumped into the fire area was, comparatively speaking, so small that it was not anticipated that any outburst of blackdamp would occur in any part of the workings that would not be adequately dealt with by the existing ventilation. Temperature measurements were already being systematically made at the various bashings, and it was arranged that one of the men performing this work should at least once in each shift make a thorough examination of the roads around the fire area and report immediately any unusual evolution of blackdamp. Several such manifestations were reported in the return near the air-bridge and near the Klondyke stables, but these were slight in extent, and were only evident near the floor. After the first week or so, these evolutions were remarkably persistent, and if stopped at one spot they immediately broke out at another; the strata were badly fissured, and it was found quite impossible to control these local outbursts.

Besides this testing with the safety-lamp, analyses of the air were made for several days in the Klondyke return. These averaged about 0·8 per cent. of carbon dioxide, so that the leakage from the point of view of ventilation was not serious.

An efficient service was already in existence for recording the temperatures at the various bashings, and this was not interfered with. After the plant had been in operation for a couple of days, a water-gauge was placed in the air-bridge in direct communication with the fire area, and the readings of this instrument were recorded together with the temperature measurements. The records obtained in this way proved in many respects not only of considerable interest, but also of considerable service in determining the conditions in the fire area.

For some days after the plant was set going, the writer paid daily visits to the colliery, and made analyses of the air inside the bashings in the Klondyke return and at the air-bridge. These analyses were made on the spot for oxygen and carbon

dioxide by means of a portable Orsat apparatus; while samples were also taken for complete analysis. These samples were aspirated by means of a Fletcher aspirator through a sampling tube of the form suggested by Dr. Haldane,* and were analysed in the colliery office by means of the Haldane apparatus. As the men in charge of the plant became more and more efficient, frequent visits to the colliery were found unnecessary. The samples were afterwards taken by a responsible official, and forwarded to the author at the Treforest School of Mines for analysis. At the outset the samples were analysed for oxygen, carbon dioxide, carbon monoxide, hydrogen, methane, and nitrogen, by a slight modification of the method suggested by Dr. Haldane in his *Methods of Air Analysis* (page 38). The carbon dioxide and oxygen were first estimated. The remainder of the sample was then bye-passed into the combustion pipette, and sufficient atmospheric air drawn in to burn the whole of the combustible constituents present. The contraction on combustion, the carbon dioxide formed, and the oxygen required for combustion were then determined, and the carbon monoxide, methane, and hydrogen were then calculated by the aid of the following equations:—

$CO + CH_4$ = percentage $CO_2$ formed by combustion.
$\frac{1}{2}CO + 2CH_4 + \frac{3}{2}H_2$ = percentage contraction.
$\frac{1}{2}CO + 2CH_4 + \frac{1}{2}H_2$ = percentage of oxygen used in the combustion.

At first the results obtained were such as to justify the assumption that the combustible gases consisted essentially of carbon monoxide, methane, and hydrogen; but, after the plant had been in operation for a day or two, the percentage of oxygen required for combustion increased so considerably in proportion to the contraction on combustion that it was evident that there was present in these combustible gases a very appreciable proportion of the higher hydrocarbons. It became a matter of some urgency, therefore, to devise a means of estimating these. Their presence evidently denoted that distillation—as distinguished from combustion—had commenced, and if a method could be devised for their estimation, it would be of considerable service in ascertaining the amount of combustion that was still taking place.

The problem of the complete estimation of the combustible

* *Methods of Air Analysis*, by John Scott Haldane, M.D., page 5.

gases was one of some difficulty, more especially as the work was being carried on in a colliery office, under works' conditions, and with a bare minimum of apparatus. It was felt that academic accuracy was not necessary: a technical analysis sufficiently detailed to allow of a distinction being made between the higher hydrocarbons and the other inflammable gases mentioned was all that was required at the time. Bearing these facts in mind, a method was devised, based on the following assumptions:—

(1) It was assumed in the first place that the temperature of combustion in the fire area was very low. Combustion was taking place in a stagnant atmosphere in the presence of an extremely small percentage of oxygen, and under these conditions it could not be expected that the temperature would exceed 500° to 700° Cent.

(2) A consideration of the results obtained by Dr. Wheeler* of the products of coal-distillation at temperatures varying from 450° to 700° Cent. show that the combustible gases consist chiefly of methane, ethane, carbon monoxide, and hydrogen. Thus at 500° Cent. the total percentage of these amounted to 88·2, and of this percentage ethane made up 27·6. The remaining inflammable gases, consisting of benzene, ethylene, and acetylene, amounted only to 6·85 per cent. Similarly at 700° Cent. the first four gases amounted to 89·5 per cent., of which 14·3 per cent. was ethane.

In view of these results, it was felt that it could be assumed with sufficient accuracy, for all practical purposes, that the higher hydrocarbons noted consisted entirely of ethane.

(3) The problem then resolved itself into a differentiation of the combustible gases into methane, carbon monoxide, hydrogen, and ethane. With the exception of methane, these gases were present only in small quantities, and ultimately it was decided to adopt a modification of the method of fractional combustion suggested by Dr. Leonard A. Levy.† This method depends on the fact that, when air containing small percentages of methane is passed over a platinum wire heated to barely visible redness, the methane is practically unaffected. The gases, hydrogen, ethane, carbon monoxide and the higher hydrocarbons—if present in small quantities—are practically burnt completely

* *Second Report of the Explosions in Mines Committee*, 1912 [Cd. 6431], page 25.
† *Journal of Gas Lighting*, 1913, vol. cxxii.. page 455.

at this temperature. The following method of analysis was therefore devised:—

After the absorption of carbon dioxide and oxygen from the original sample, sufficient air was added to ensure the combustion of the various combustible gases, and to allow of a small excess of oxygen. The resulting mixture was then passed over a platinum wire heated to barely visible redness, and the contraction on combustion and carbon dioxide formed was estimated. A second combustion at this temperature was afterwards made, and the corresponding measurements taken. The temperature of the platinum wire was then raised to white heat, and a similar series of determinations made. In this case the carbon dioxide formed was invariably (within the limits of experimental error) half the contraction on combustion, and thus this gas was regarded as pure methane. Assuming that the gases consumed in the first combustion consisted of carbon monoxide, hydrogen, and ethane, their relative proportions could be readily calculated from the following equations:—

$2CO + O_2 = 2CO_2$.
$2H_2 + O_2 = 2H_2O$.
$2C_2H_6 + 7O_2 = 4CO_2 + 6H_2O$.
Let $x$ = percentage of carbon monoxide.
,, $y$ = ,, ,, hydrogen.
,, $z$ = ,, ,, ethane.

Then—

$x + 2z$ = percentage of carbon dioxide formed by combustion at low temperature.

$x + 3y + 5z = 2 \times$ percentage-contraction.

$x + y + 7z = 2 \times$ percentage of oxygen absorbed by low-temperature combustion.

The solution of these three simultaneous equations gives the values required.

The following numerical example serves as an illustration of the method:—

SAMPLE OF GAS FROM FIRE ZONE, TAKEN ON MARCH 20TH, 1914.

| | | Cubic Centimetres. |
|---|---|---|
| | Original volume ... ... ... ... | 20·023 |
| Percentage of $CO_2$, 18.65. | Volume after absorption of $CO_2$ ... | 16·289 |
| | Volume of $CO_2$ ... ... ... ... | 3·734 |
| Percentage of oxygen, 1·79. | Volume after absorption of oxygen ... | 15·930 |
| | Volume of oxygen ... ... ... | 0·359 |
| | Volume after addition of air ... ... | 20·250 |

| | | Cubic Centimetres. |
|---|---|---|
| | Volume of air added ... ... ... | 4·320 |
| | ∴ Volume of oxygen added ... ... | 0·903 |
| | Volume after first combustion at low temperature ... ... ... ... | 20·150 |
| | ∴ Contraction ... ... ... ... | 0·100 |
| | Volume after $CO_2$ was absorbed ... | 20·090 |
| | $CO_2$ formed ... ... ... ... | 0·060 |
| | Volume after second combustion at low temperature ... ... ... ... | 20·070 |
| | Second contraction... ... ... ... | 0·020 |
| | Volume after $CO_2$ formed was absorbed | 20·059 |
| | Volume of $CO_2$ formed ... ... ... | 0·011 |
| | Volume after combustion at white heat | 19·739 |
| | Contraction ... ... ... ... | 0·320 |
| | Volume after absorption of $CO_2$ ... | 19·584 |
| Percentage of methane, 0·91. | Volume of $CO_2$ formed ... ... ... | 0·155 |
| | Volume after second combustion at white heat ... ... ... ... | 19·539 |
| | Second contraction ... ... ... ... | 0·045 |
| | Volume after $CO_2$ formed was absorbed | 19·510 |
| | $CO_2$ formed ... ... ... ... ... | 0·029 |
| | Volume after the residual oxygen was absorbed ... ... ... ... | 19·057 |
| | Residual oxygen ... ... ... ... | 0·453 |

Volume of oxygen added = 0·903.
,, ,, residual oxygen = 0·453.
,, ,, oxygen used for combustion = 0·450.
,, ,, oxygen used for combustion of methane = 0·366.
∴ Volume used for combustion of $C_2H_6 - H_2 + CO = 0·084$.
$x + 2z$ = percentage of $CO_2$ formed by low-temperature combustion = 0·35.
$x + 3y + 5z = 2 \times$ percentage-contraction after low-temperature combustion = 1·20.
$x + y + 7z = 2 \times$ percentage of oxygen used for low-temperature combustion = 0·840.
∴ $x$ = percentage CO = 0·25.
$y$ = ,, $H_2$ = 0·23.
$z$ = ,, $C_2H_6$ = 0·05.

∴ Analysis of sample (March 20th, 1914):—

| | Per cent. |
|---|---|
| Methane ... ... ... ... ... ... ... | 0·91 |
| Carbon dioxide ... ... ... ... ... ... | 18·65 |
| Oxygen ... ... ... ... ... ... ... ... | 1·79 |
| Carbon monoxide ... ... ... .. ... ... | 0·25 |
| Hydrogen ... ... ... ... .. ... ... | 0·23 |
| Ethane ... ... ... ... ... ... ... ... | 0·05 |
| Nitrogen ... ... ... ... ... ... ... | 78·12 |

From a strictly academic standpoint some objections might be urged against this method. Even at low temperatures the catalytic action of platinum is apt in time to cause the ignition of a portion of the methane, while the combustion of the hydrogen and other gases on the surface of the wire might conceivably raise the temperature sufficiently to consume a portion of the methane. Further, the temperature of combustion of carbon monoxide is fairly high, and in the presence of fairly large quantities of this gas—2 to 3 per cent.—its combustion at low temperatures is probably imperfect.

It was found, however, in the gases analysed, that no evidence presented itself to justify this latter hypothesis, and the combustible gas present after the preliminary combustion in every case gave the indications expected of pure methane. Further, in a series of preliminary experiments it was found (provided that the temperature were kept sufficiently low) that in specially-prepared mixtures no indications could be obtained of the combustion of methane at low temperatures. This was consistently the case when the total combustible gases did not exceed 2·5 per cent.

The precaution was taken in every analysis to heat the spiral for one minute only to a temperature of barely visible redness, the regulation being made by a finely-adjusted rheostat, while the second combustion at the same temperature was made for only 30 seconds. Several duplicate determinations for carbon monoxide were made with the blood test, and gave concordant results. This test, however, was found rather troublesome with the mixtures involved, and was ultimately abandoned.

The method of analysis described above gave results that in every case preceded temperature measurements, and proved of the utmost value in determining the conditions existing in the fire zone. The principal difficulty connected with it was the necessity for making an extremely accurate determination of the residual oxygen, and it was found necessary, before such estimation, to make a series of determinations of atmospheric air in the Haldane apparatus with the view of testing thoroughly the freedom of the instrument from even minute leakages.

*Operation of the Carbon-dioxide Plant.*—The plant was set in operation on December 10th, 1913, the gas being injected

at the out-bye bashing. For some distance on the main intake inside this bashing (in the fire area) very heavy falls had taken place, and, in order to find a suitable place for the injection of the carbon dioxide, some of the sand-bags were removed from the top of the bashing, and the opening thus made tested with a "smoke-box" for a fissure or cavity into which the gas could be pumped. The "smoke-box" was lent by Dr. W. N. Atkinson, and proved a most efficient little instrument for the detection of leakage. It consisted essentially of two wash-bottles connected in series, one containing hydrochloric acid and the other ammonia. By blowing air through these a dense white cloud of ammonium chloride was produced, by means of which a leakage in the strata surrounding the fire zone could be readily discovered. With the aid of this apparatus, a fissure was soon discovered which could easily take the whole of the carbon dioxide generated by the plant, even when that was working at top speed. A pipe was laid in communication with this fissure communicating with the carbon-dioxide plant, and the opening around it completely closed up with sand-bags, so as to prevent any leakage of air. The bashing and strata around it were throughout the whole of the operations continually tested for blackdamp, but no trace of this was discovered at the intake side.

The plant was set going at 10 a.m. on December 10th, 1913, and was charged every 2½ hours, producing about 350 cubic feet of carbon dioxide per hour. The pipes were cleared of air before the plant was placed in communication with the fire area, and the usual precautions were taken so as to obviate the possibility of any leakage of air taking place.

Owing to the work involved in the erection of the generating plant, it had been found impossible to make an analysis of the air between December 6th and 12th, but an analysis at the air-bridge was made at 1 p.m. on December 10th by means of a portable Orsat apparatus. This analysis (made three hours after the plant had started) gave a carbon-dioxide content of 12 per cent., a result practically identical with that of December 6th, consequently the probability was that very little change had taken place.

At 5 p.m. on the same date a further analysis showed the amount of carbon dioxide as 13·5 per cent. (a slight increase)

and the oxygen as 5·2 per cent. Analyses were also made near the Pretoria bashing and in the Klondyke return, but no serious effect could be observed on the ventilating current. By 8 a.m. on the following morning the carbon dioxide had increased to 17·8 per cent., while the oxygen had decreased to 3 per cent., a thoroughly satisfactory result for 24 hours' working. Meanwhile, outbursts of blackdamp had been reported in the return near the air-bridge, and also in the Klondyke return, and these outbursts persisted throughout the whole period of the operations. They were, however, purely local, and did not affect the ventilation to a serious extent; but they gave evidence of the leakage that was taking place in the strata surrounding the fire area.

Practically no difference had taken place in the temperatures either at the air-bridge or at the Klondyke bashing. The temperature on the out-bye side of the air-bridge was 126° and on the in-bye side 96° Fahr., while the temperature at the Klondyke bashing fluctuated with the "breathing" of the fire between 136° and 142° Fahr. Incidentally this temperature of 140° persisted for nearly the whole period of operations at the Klondyke bashing, and it was only towards the close that it commenced to fall. Further, it was the maximum temperature attained at the air-bridge during the period that the bashings were in place. This figure is rather significant, in view of the fact that Fayol repeatedly obtained the same figure in his classical research on the spontaneous combustion of coal.

Very little difference was shown either in the temperatures or in the analyses during the two following days. On December 12th the analysis gave—carbon dioxide 16·9 and oxygen 3·0 per cent., whilst the figures on the 13th were—carbon dioxide 17·26 and oxygen 2·61 per cent. From this time forward the carbon dioxide increased only slightly, and at no time during the progress of operations did the percentage of carbon dioxide exceed 19·2. It is distinctly evident that considerable leakage was taking place. The leakage outwards in the Klondyke return and near the air-bridge has already been mentioned, and this could not be overcome. In the Klondyke return especially the task proved of enormous difficulty. The heated strata often gave way, and falls occurred repeatedly, leaving cavities of considerable size, out of which came large volumes of steam and

blackdamp. In order to cope with these, the work of arching the roadway and facing it with concrete was commenced, but this proved a most difficult task. So soon as a section of the roadway was completed, the weakened strata immediately adjacent to it gave way, and ultimately it was found necessary to extend the arching for a considerable length.

This leakage in the Klondyke return played a very important part in keeping combustion going. The evolution of blackdamp and steam caused a considerable reduction of pressure in the fire area, and this was but partly counterbalanced by the comparatively small quantity of carbon dioxide that was continually being pumped in. There was considerable excess pressure on the intake side, and in consequence considerable leakage of air inwards took place. This was especially the case in the area immediately around the out-bye bashing. For about 30 yards on either side of this the "smoke-box" showed evidence of very serious leakage. The strata were permeated with fissures and crevices, and inward leakage of air was taking place through practically all of these. The cumulative effect, therefore, was that there was a short-circuiting of air through the strata from the intake to the return, and this slow current of air was sufficient to keep combustion proceeding for an indefinite period. Further, this short-circuiting was increased by any meteorological changes, or changes in ventilation, that increased the difference in pressure between the intake and the return.

To some extent the continuous current of carbon dioxide pumped in assisted to counterbalance these factors, and it did so in three ways, namely:—

(1) It reduced the oxygen content of the air passing through the fire area.

(2) It assisted to some extent in maintaining the pressure in the fire area, and thus reducing the leakage.

(3) It damped fluctuations of pressure in the fire area.

That this process was to some extent taking place is shown by the analyses already given, but after the first 24 hours' working a condition of equilibrium had been produced, in which the amount of carbon dioxide injected, and the amount of blackdamp leaking outwards, were practically equal.

Meanwhile a difficulty had arisen in the course of the analytical work. Samples of the gas from the fire area analysed

for carbon monoxide, methane, and hydrogen had given the following results for the combustion:—

| Sample. | December 12th, 1913. Per cent. | December 13th, 1913. Per cent. |
|---|---|---|
| Carbon dioxide produced by combustion | 1·415 | 1·445 |
| Contraction on combustion .. .. | 2·302 | 2·100 |
| Oxygen absorbed by combustion .. .. | 2·493 | 2·305 |

These figures are quite impossible if the only combustible gases present were hydrogen, carbon monoxide, and methane. The only way in which they can be accounted for is by the assumption that higher hydrocarbons were present in the sample. Supplementary samples were, therefore, taken, with the view of subsequent examination, and were later analysed by the method of fractional combustion already described. They then gave the results recorded under those dates in the Appendix.

The reduced percentage of carbon monoxide in these analyses shows that combustion was decreasing, whilst the percentage of ethane present indicates that distillation had begun to predominate over combustion. Nevertheless, the temperatures at the air-bridge and at the Klondyke bashing had as yet showed no evidence of diminution, but this was not to be expected after so short a time. The analytical results, however, were so satisfactory that it was hoped that these would soon begin to respond to the improved conditions.

Unfortunately, a serious alteration in the condition of things took place on December 13th, 1913. The work of clearing and exploring the various districts on the western side of the colliery was still proceeding, whilst one or two of the districts were full of firedamp, which could not be cleared by the modified system of ventilation then in use. An official inspection of the Ladysmith district was to take place on December 16th, and, in order to clear this district of gas, the doors in the main intake were opened, and the ventilating current was allowed to take the course described on page 212. The air-pressure against the out-bye bashing was immediately increased, and the following series of determinations show clearly the changes produced:—

TEMPERATURE AND WATER-GAUGE MEASUREMENTS ON DECEMBER 13TH, 1913.

| Time. | Temperatures at air-bridge. | | Water-gauge. | Remarks. |
|---|---|---|---|---|
| | Out-bye. | In-bye. | | |
| December 13th, 1913. | Degs. Fahr. | Degs. Fahr. | Inches. | |
| 7·15 a.m. | 126 | 104 | 0·90 | The ventilation was changed at 3·40 p.m. The water-gauge immediately increased to 1·2 inches, decreased to 1 inch, and afterwards rose at 4·30 p.m. to 1·1 inches. |
| 8·15 „ | 126 | 100 | 0·95 | |
| 9·45 „ | 127 | 100 | 0·90 | |
| 10·45 „ | 124 | 100 | 1·00 | |
| 12·0 noon. | 126 | 98 | 1·00 | |
| 1·15 p.m. | 126 | 100 | 0·95 | |
| 3·15 „ | 130 | 100 | 0·95 | |
| 4·30 „ | 134 | 110 | 1·10 | |
| 5·40 „ | 137 | 126 | 1·10 | |
| 6·45 „ | 139 | 130 | 1·20 | |
| 8·10 „ | 139 | 130 | 1·20 | |
| 9·45 „ | 140 | 133 | 1·10 | |
| 11·0 „ | 139 | 134 | 1·20 | |
| 12·0 „ | 139 | 134 | 1·20 | |

The water-gauge readings in particular are extremely interesting. The sudden jump was due to the sudden increase of pressure. The fall afterwards was probably due to the cooling action of the air-current (the air temperature on the surface was about 36° Fahr.) on the strata. This was conducted to the fire zone, producing a condensation of some of the water-vapour and causing a reduction in pressure. It is evident from the increase of temperature on the in-bye side of the air-bridge that a current of air had been produced, probably from the out-bye bashing to the Pretoria bashing, and this caused an increase of combustion, and therefore of temperature, which ultimately raised the air-pressure (as shown by the water-gauge) to 1·2 inches.

The analyses for the next few days are rather interesting. The sudden increase in combustion on December 14th is shown by the increase in the percentage of carbon monoxide, while simultaneously the increase in the percentage of hydrogen probably indicates an increase in the temperature. The increased oxygen content also shows an increased amount of leakage.

The sudden increase in the temperature proved a very severe strain to the old boiler of which the air-bridge was constituted, and it was feared that this would collapse with a consequent serious derangement of the ventilation. It was strengthened as far as possible with iron stays, but it still showed signs of

giving way, and on December 15th the former system of ventilation was restored. The water-gauge at once fell from 1·1 to 0·8 inch, and the temperature at the air-bridge began to fall slowly until by December 19th the readings at the in-bye and out-bye side of the air-bridge were 116° and 126° Fahr. respectively.

From December 17th, 1913, to January 20th, 1914, the analyses showed that a considerable amount of combustion was taking place. These analyses present several points of interest. In the first place, the samples from December 19th, 1913, until January 20th, 1914, showed no evidence of ethane. The percentage of hydrogen was also either very low or else it was completely absent; but there was present a considerable quantity of carbon monoxide, pointing to active combustion. Over and over again during the progress of this work an increased percentage of carbon monoxide coincided with decreased percentages of hydrogen, ethane, and even methane, and this seems to indicate that the initial effect of increased combustion in a mine fire is to burn off the combustible gases, possibly (as Dr. Harger has suggested) by a process of surface combustion. When the period of active combustion is drawing to a close, the hydrogen and methane first make their appearance, and finally the ethane. The hydrogen, however, gradually diminishes, while the methane and ethane slowly increase. The hydrogen is a product of high-temperature distillation, ethane is a product of low-temperature distillation, whilst methane is produced both by high-temperature and low-temperature distillation. Thus, a high percentage of hydrogen is evidence of high temperature produced after a period of active combustion, whilst a high percentage of ethane offers distinct evidence both of the absence of combustion and of a fairly low temperature.

It will be noted also in these analyses that the carbon dioxide had risen to between 18 and 19 per cent., whilst the oxygen had been reduced to between 1·3 and 2·1 per cent. This can be accounted for partly by increased absorbtion of oxygen and increased production of carbon dioxide owing to the more active combustion; but it is also due to the fact that, in order to cope with the increased combustion, the carbon dioxide was increased on December 17th to between 500 and 600 cubic feet an hour. It was found that an increased quantity of carbon dioxide mani-

fested itself immediately in a reduction of the oxygen content, rather than in an increase in the carbon-dioxide percentage. This was invariably most appreciable during the first 24 hours after the increase, but after that a period of equilibrium set in, the leakage adjusted itself to the new conditions, and no further reduction in the oxygen or increase in the carbon dioxide manifested itself, unless a change in the conditions occurred to produce a change in the position of equilibrium. It was becoming distinctly evident at Senghenydd that the extinction of the fire was a matter depending primarily upon pressures, and it became of some importance to determine the various factors involved and the influence of those factors upon combustion. Before proceeding to discuss these in the light of the results obtained at Senghenydd, it might be as well to consider at this point the various influences that theoretically might have a bearing upon the progress of operations.

*Factors Influencing the Propagation of Mine Fires.*—It is evident that there are primarily two opposing factors involved, namely: (*a*) the leakage of air into the fire area opposed by (*b*) the pressure of the gases generated by the fire. This at Senghenydd was assisted by the continuous input of a small but regular supply of carbon dioxide.

The leakage of air into the fire area is dependent upon the following factors:—

(1) Extent of the fissures in the strata communicating with the fire area.

(2) The breathing action of the fire.

(3) The outward pressure of gases in the fire area.

(4) The difference in pressure between intake and return.

(1) *Extent of the Fissures in the Strata.*—For the present it would be better to regard these as a constant factor while their influence is so obvious that they can be disregarded in the ensuing considerations.

(2) *The Breathing Action of the Fire.*—This has already been mentioned, and is of the utmost importance. It is absolutely necessary that this should be stopped before any progress can be made. As will be shown later, a small but continuous input of inert gas has a considerable effect in bringing about a cessation of this action.

(3 and 4) *The Pressure of Air* in the intake, return, and in the fire area is dependent upon a number of factors—chemical, mechanical, and meteorological. The principal variables can be treated under the following headings:—

(1) The influence of barometric fluctuation.

(2) The influence of fluctuations in atmospheric temperature.

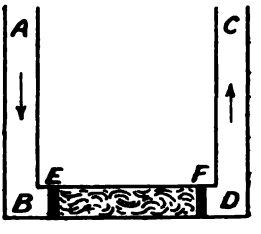
(3) The influence of changes in atmospheric humidity.

(4) The influence of changes in ventilation.

(5) The influence of the chemical actions proceeding in the fire area.

This latter is to some extent synonymous with the breathing action, and therefore need not be treated fully. It is, however, touched upon in the following paragraphs:—

(1) *The Influence of Barometric Fluctuations.*—This can be readily gathered by a consideration of the following elementary illustration. Supposing *A-B* and *C-D* represent respectively the downcast and upcast shafts of a mine with a fire raging in a cross-cut sealed off by stoppings at *E* and *F*, then let these stoppings be regarded as reasonably but not absolutely airtight. Supposing a *sudden* fall in atmospheric pressure occurs: a reduction of pressure would occur at *B* and *D*, and, since the leakage at *E* and *F* is not considerable, the effect of this fall would be an apparent increase of pressure in the fire area, which would be immediately shown on a water-gauge, say at *F*, communicating on the one side with the fire area, and on the other with the return.




On the other hand, with a *sudden* rise in the barometric pressure there would be an apparent fall in the pressure in *E F*. Thus, with rapid rises in barometric pressure, there would be increased leakage into the fire area, while with rapid falls there would be increased evolution of blackdamp outwards. In both these cases fluctuations in pressure would occur, which would be shown on a water-gauge communicating with the fire zone. Slow barometric fluctuations, however, would not be shown on a water-gauge, as the changes would be counterbalanced almost as they occurred by leakage.

(2) *The Influence of Changes in Atmospheric Temperature.*—This factor leads to somewhat complicated phenomena. Sup-

posing that an abrupt fall occurs in the atmospheric temperature, the temperature of the return air in a deep mine would be constant; therefore, with the greater difference in temperature between intake and return, there would be a greater difference in pressure between the two. If the previous illustration is taken as an example, a water-gauge placed at *F* would show a static increase of pressure. Further, with the increased difference in pressure between intake and return, a dynamic action would occur, and an increased quantity of air would pass through the fire area. This in its turn would produce increased combustion, which would also increase the pressure in the fire area. This increase in pressure would continue so long as the fall in temperature continued. Then, however, a condition of equilibrium would set in, the increased pressure in the fire area would to some extent reduce the leakage, and combustion would slacken. If, now, the temperature began to rise, this would show itself by a drop in the water-gauge between the fire area and the return. The pressure difference between intake and return would be reduced, the quantity of air short-circuiting from intake to return would decrease, and with this reduced leakage combustion would decrease. Thus the ultimate effect would be increase of combustion with decrease of temperature, and *vice versâ*.

It may be mentioned here that this was found to be the case at Senghenydd. A snap of cold weather accelerated combustion to a marked extent, whilst a fairly prolonged spell of mild weather was invariably accompanied by favourable analytical results. The increased combustion between December 19th, 1913, and January 16th, 1914, was due to a sharp fall in the atmospheric temperature. An impulse had already been given to combustion by the change in ventilation of December 13th, and this, with the additional leakage caused by the cold weather, caused a serious outburst of combustion, which did not begin to diminish until January 16th.

(3) *The Influence of Changes in Atmospheric Humidity.*—Theoretical considerations point to the fact that atmospheric humidity would have an appreciable effect on mine fires. No observations, however, were made at Senghenydd with regard to this point and in the absence of such records it would be inadvisable at present to do more than point out the possibility of this influence.

(4) *The Influence of Changes in Ventilation.*—The balance of pressure between intake and return is often seriously affected by changes in ventilation, and an instance of this has already been given. There are, however, a number of smaller variations which may produce appreciable differences in pressure, with consequent appreciable differences in the amount of leakage. The opening of doors, variations in the speed of the fan, falls in the fire area, and the small changes of ventilation that daily take place in every colliery—all these innumerable small factors, although possibly unimportant in themselves, have quite an appreciable cumulative effect on the progress of a mine fire.

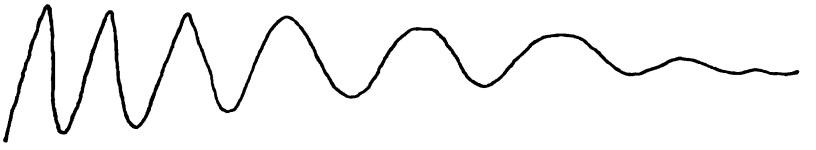
It is now possible to consider these various factors in their relation to the Senghenydd fire, and to study the effect of the supply of inert gas upon these various influences. It is better perhaps to consider them in the light of the water-gauge readings obtained at the air-bridge, and for purposes of comparison these readings have been plotted (Fig. 6, Plate V.) and correlated with observations of atmospheric temperatures and pressures.

*The Water-gauge and the Senghenydd Fire.*—This water-gauge was fixed on December 12th, 1913, and represented the difference in pressure between the fire area and the return. Readings were taken every hour, and these are plotted on the chart (Fig. 6, Plate V.) against a curve of barometric pressures and daily maximum and minimum temperatures. Unfortunately, no record of the atmospheric temperatures was compiled at the colliery, and the temperatures and barometric pressures recorded were those made at the Cardiff Meteorological station about 10 miles away, and reproduced by the kind permission of Dr. Walford, Medical Officer of Health for Cardiff. Senghenydd is about 800 feet above Cardiff, and both the barometric readings and the temperature measurements were probably consistently lower at that place than at Cardiff. The changes of temperature and pressure would, however, correspond very closely in both places, and therefore the shape of both curves is probably representative of the conditions at Senghenydd.

The readings of the water-gauge were taken hourly; from December 12th onwards, the barometric pressures were taken twice a day (at 9 a.m. and 9 p.m.),while the maximum and minimum temperatures were taken daily, and for purposes of compar-

ison both the maximum and the minimum for each day has been drawn as a 24-hour period. In the absence of hourly temperature records, it was considered that this was the most satisfactory method of plotting the results, whilst a mean-temperature curve has also been drawn, which brings out the same results as those shown by the maxima and minima readings. A number of interesting points are brought out by a study of this curve, which can be summarized as follows:—

(1) *The Water-gauge and Combustion.*—A survey of the water-gauge curve as a whole shows that it is an oscillatory curve of the following form:—



The period of greatest fluctuations is at the beginning of the curve, whilst from January 16th a gradual damping action has taken place. The violent fluctuations correspond to the period of excessive combustion, as shown by analysis. Unfortunately, the results from December 20th, 1913, to January 7th, 1914, are missing; but, from the appearance of the curve from December 13th to 20th and from January 7th to January 16th, there is every probability that the intervening portion would be of a similar highly fluctuating character. The changes of ventilation on December 13th and 15th are shown clearly, and the excessive character of the fluctuations until January 16th are due to the breathing action that was taking place. On December 19th it will be noted that the water-gauge increased momentarily to 1·5 inches, while a similar result was obtained on February 7th. These changes might be caused either by temporary changes in ventilation which have not been recorded, or more probably by heavy falls taking place in the fire zone, causing a momentary increase of pressure.

It will be noted that the damping effect first begins to manifest itself on January 15th, and it will be remembered that it was on January 16th that an analysis first gave any indication of cessation of combustion. From January 16th to January 20th the fluctuations become much less marked in character, a condition in perfect agreement with the excellent analytical results obtained on January 20th.

From January 20th to January 23rd was another period of marked fluctuation, which does not correspond to any atmospheric pressure or temperature changes. This probably implies that a fresh outburst of combustion had occurred, a result also shown by the analysis on January 25th.

The increased percentage of carbon monoxide and the decreased percentages of methane and ethane all point to the same conclusion—increased combustion. Incidentally it may be mentioned that on January 20th about 50 per cent. of the carbon dioxide had been diverted to the air-bridge, and was injected at that point as well as at the out-bye bashing.

The curve shows very little fluctuation from January 23rd until the 31st, while an analysis of a sample taken on the 29th gave results which seemed to indicate no combustion whatever.

A slight outburst is noticeable on January 31st, and another on February 5th. The high percentage of both carbon monoxide and hydrogen in the analysis of the sample taken on that date probably indicates that the outburst of combustion was nearing the end, and the fairly steady character of the curve until February 12th points in the same direction. The high percentage of oxygen in the analysis of February 12th, together with the low percentage of the combustible gases other than methane, indicate a minimum of combustion.

The curve then remains fairly steady until February 23rd, when a rather serious depression of the water-gauge occurred, followed by marked fluctuation. The reduction of pressure probably caused serious leakage, which again set combustion going, whilst the high percentage of carbon monoxide in the sample taken on February 26th indicated a rather serious outburst. In order to cope with this, the quantity of carbon dioxide was increased to 1,000 cubic feet an hour, and kept at that amount for about three days. This had the desired effect, and by March 1st the water-gauge curve shows that matters were again becoming normal. Very little fluctuation occurs in the curve from March 1st onwards, and there is no doubt that combustion had decreased to a minimum; a conclusion in keeping with the highly-improved analysis of March 20th. The carbon-dioxide plant was stopped on March 28th, but the series of analyses made between that date and June 26th gave practically no indications of combustion.

The general character of the curve indicates that the constant addition of the carbon dioxide exerts a small but continuous check on the violent fluctuations produced by the breathing action of the fire. The extremes of pressure gradually approach more closely together, until finally the graph—considered apart from the other influences—tends to become a straight line.

(2) *The Water-gauge and Atmospheric Temperatures.*—The relation between changes in atmospheric temperatures and the water-gauge is clearly shown on the chart. The curves of temperatures and pressures are symmetrically opposite to one another, the water-gauge rising with a decrease in atmospheric temperature, and falling with a rise. Thus the "upward loop" in the temperature curve between January 7th and January 11th corresponds with the downward loop in the water-gauge between the same dates. Similar results are shown between January 23rd and February 9th, between February 11th and February 17th, and between March 10th and March 18th.

Further, as a general rule, greater fluctuations occur in the depressions of the water-gauge curve than in the elevated portions. This can be readily understood by the fact that these depressions represent periods of low pressure during which leakage from the intake side would be greater than under normal conditions, and this leakage would be followed by greater combustion.

(3) *The Water-gauge and Barometric Variation.*—In very few instances can the effect of barometric variation be perceived. This was only to be expected, as slow movements would be readily counteracted by leakage, and only very rapid rises or falls in the barometric pressure would be shown. One particular instance of a marked character occurs on February 2nd, where a rapid rise of barometric pressure begins. This was followed by an abrupt fall in the water-gauge readings, succeeded by a slow rise lagging some hours after the barometric rise. It will be remembered that in this case the rapid decrease in pressure in the fire area produced for a short time a serious renewal of combustion. Some similar instances can be noted in the sudden barometric fluctuations during the period March 8th to 26th, while, speaking generally, the water-gauge curve shows a distinct lag after the barometric curve.

(4) *Changes of Ventilation and Miscellaneous Factors.*—The

effects of big changes of ventilation have already been commented on, and need not be discussed further, but the effect of such factors as the opening of doors, etc., can (to some extent) be gathered from the chart. It will be noted that, as a general rule, the most marked fluctuation each day—especially when the temperature and barometric effects can be eliminated—occur between 9 p.m. and 3 a.m. In many instances several fluctuations of about 0·05 inch occur in these few hours: January 24th, 28th, and 29th, February 3rd and 4th are cases in point. It was during the night that the whole of the chemicals for the following 24 hours were taken to the plant, and during this period the doors were opened far more frequently and to a greater extent than during the day-time, so that small fluctuations in the water-gauge occurred far more frequently than during the day. Of course, the water-gauge was only read hourly, but there is no doubt from personal observation that this is the case.

From a general standpoint, the water-gauge is a most valuable instrument in the detection and control of mine fires. Preferably it should be of a recording type, and its readings should be correlated as far as possible with the readings of a recording barometer and with readings of atmospheric temperature.

If supplemented with periodic chemical analysis, the information so obtained would, in the writer's opinion, be far more comprehensive in character than temperature measurements alone.

*Summary and Conclusions.*—The effect of a comparatively small but regular quantity of inert gas pumped into a fire area can now be readily understood. Its chief effect lies, not so much in its extinguishing power, as in its gradual damping down of pressure changes in the fire area. These pressure changes are produced by the breathing nature of the fire, by changes in ventilation, and by changes in atmospheric temperature and pressure; and it is the leakage of air resulting from these changes that allows combustion to proceed. Dr. Harger has evidently been working on somewhat similar lines, because he states that "the quantity of gas required is comparatively small, being just sufficient to correct the changes in atmospheric pressure, and to counteract any short-circuiting across the wastes." Unfortunately (so far as the writer is aware) his

results have not yet been published, but it would be of interest to know how far they are in agreement with the results of the present investigation.

Provided that leakage is reduced to a minimum, it is then only a matter of time before combustion will be absolutely extinguished, the length of time depending on the extent of the fire and the magnitude of the inevitable leakage. Unfortunately, however, inert gas has a rather serious limitation, a limitation that was pointed out by Mr. W. H. Chambers nearly twenty years ago.* There is no doubt that in time it can extinguish a mine fire, but it can only reduce the temperature by a very slight extent, unless it is used in the liquefied form, and in such quantities that its vaporization will absorb sufficient heat to reduce the temperature to normal. Under such conditions, and injected at a number of different points, it has proved efficacious both in the extinction of combustion and in the reduction of temperature in the case of very large fires in the holds of ships. In such cases a quantity varying from 4,000 to 10,000 cubic feet of carbon dioxide is injected in a few hours through pipes already fitted around the hold of the ship, and several instances are on record of exceedingly rapid temperature reductions even when masses of coal amounting to thousands of tons have been on fire.

Probably difficulty would be found in mining practice in applying the liquid carbon dioxide at a sufficient number of points to produce an adequate reduction of temperature at every part of the burning mass in order to ensure its extinction. The temperature difficulty, therefore, will always be a serious one in mining practice. The only outlet for the temperature is by conduction through the strata, and the enormous store of heat in a large mine fire might possibly take several years to dissipate. This was the difficulty experienced at Senghenydd. Despite the favourable analytical results, the temperature measurements were falling so very slowly that the management always had present to their minds the possibility that combustion would start again. It was, therefore, decided to adopt other measures, with the view of preventing absolutely the possibility of any future recurrence of combustion. It is outside the province of this paper to go into the details of the methods adopted, but an

* "Notes on Gob-fires," *Trans. Inst. M.E.*, 1899, vol. xviii., page 154.

idea can be obtained from Fig. 7 (Plate V.), which is reproduced by the kind permission of Mr. Shaw, the Manager of the Senghenydd Colliery. The outside bashing was opened during the last week in July, 1914, and the analyses of samples taken on July 24th and August 17th show that combustion restarted immediately.

It might, perhaps, be mentioned that the carbon-dioxide plant was of considerable service during the progress of these operations, chiefly as a means of keeping the fire back from the vicinity of the air-bridge. So soon as the temperature at this point became excessive, carbon dioxide was injected, and invariably effected a reduction to reasonable limits within a comparatively short period of time. The extent of the fire may be gathered from the following quotation extracted from a communication of Mr. Shaw to the author:—

"About 12 yards above the road in which the fire occurred is a seam of coal, and we found that this seam was on fire for over 250 yards in length; then 12 yards above this seam is the 4-foot seam, and this was also on fire; the 2-foot 9-inch seam is 10 yards above the 4-foot seam, and the fire had got to within 2 yards of this, so that the whole strata to a height of 32 yards above the roadway was on fire. I found that stone would burn nearly as well as coal, particularly beds of black rashings."

With a mass of burning material of this magnitude, in ground permeated with crevices and fissures, and with a consequent enormous leakage, it is a matter for surprise that the injection of carbon dioxide was able to accomplish as much as it did; but ultimately, to quote Mr. Shaw again, "it was water and perseverance that put the fire out, and it required big quantities of both."

The author, in conclusion, begs to acknowledge his indebtedness to Mr. W. T. Rees, Managing Director of the Lewis Merthyr Collieries, for his kind permission to publish the results obtained; to Mr. Edward Shaw and his staff for some of the plans submitted, and for much valuable information; and to the Principal and staff of the South Wales School of Mines, Treforest, for their whole-hearted co-operation and advice, both in the conduct of the operations at Senghenydd and in the preparation of the charts and diagrams accompanying this paper.

APPENDIX.—Analyses of Samples of Gas from the Fire Area at Senghenydd Colliery, October 21st, 1913, to August 17th, 1914.

| Date. | Place collected. | Methane. | Carbon dioxide. | Carbon monoxide. | Hydrogen. | Ethane. | Oxygen. | Nitrogen. |
|---|---|---|---|---|---|---|---|---|
| 1913. | | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Oct. 21 | Over falls near roof | 0·02 | 4·22 | 1·03 | 0·49 | — | 16·00 | 78·24 |
| ,, 21 | Near floor | 0·01 | 6·84 | 0·83 | 0·33 | — | 13·40 | 78·59 |
| ,, 25 | ,, | 0·30 | 6·25 | 1·14 | 0·68 | — | 14·15 | 77·48 |
| ,, 25 | ,, | 0·40 | 6·40 | 0·95 | 0·58 | — | 13·89 | 77·78 |
| Nov. 10 | ,, | 0·20 | 0·60 | 0·04 | — | — | 20·46 | 78·70 |
| ,, 25 | Air-bridge | 0·58 | 13·08 | 0·72 | 0·48 | — | 6·43 | 78·71 |
| Dec. 6 | ,, | 0·56 | 12·66 | 0·51 | 0·30 | — | 6·13 | 79·84 |
| ,, 12 | ,, | 0·80 | 16·90 | 0·17 | 0·04 | 0·22 | 3·00 | 78·87 |
| ,, 13 | ,, | 0·75 | 17·26 | 0·37 | 0·03 | 0·19 | 2·61 | 78·79 |
| ,, 14 | ,, | 0·70 | 15·41 | 0·60 | 0·35 | 0·10 | 3·82 | 79·02 |
| ,, 15 | ,, | 0·75 | 16·50 | 0·50 | 0·36 | 0·09 | 3·02 | 78·78 |
| ,, 17 | ,, | 0·80 | 16·80 | 0·45 | 0·48 | 0·18 | 3·10 | 78·19 |
| ,, 19 | ,, | 0·85 | 19·00 | 0·50 | 0·33 | 0·03 | 1·71 | 77·58 |
| ,, 23 | Klondyke | 0·72 | 19·00 | 0·60 | 0·36 | — | 2·10 | 77·22 |
| ,, 26 | Air-bridge | 0·60 | 18·80 | 0·80 | 0·29 | — | 2·10 | 77·41 |
| ,, 29 | ,, | 0·72 | 19·00 | 0·69 | 0·14 | — | 2·03 | 77·42 |
| ,, 31 | ,, | 0·68 | 18·40 | 0·64 | 0·08 | — | 2·18 | 78·02 |
| 1914. | | | | | | | | |
| Jan. 3 | ,, | 0·92 | 19·11 | 0·65 | 0·15 | — | 1·20 | 77·97 |
| ,, 3 | Klondyke | 0·76 | 18·60 | 0·50 | — | — | 2·00 | 78·14 |
| ,, 9 | Air-bridge | 0·96 | 18·70 | 0·75 | 0·18 | — | 1·32 | 78·09 |
| ,, 12 | ,, | 1·10 | 18·71 | 0·62 | 0·10 | — | 1·70 | 77·77 |
| ,, 16 | ,, | 1·30 | 18·10 | 0·45 | 0·18 | — | 1·51 | 78·46 |
| ,, 20 | ,, | 1·50 | 18·30 | 0·20 | 0·31 | 0·16 | 2·00 | 77·53 |
| ,, 25 | ,, | 1·37 | 18·15 | 0·38 | 0·31 | 0·07 | 1·53 | 78·19 |
| ,, 29 | ,, | 1·51 | 18·22 | 0·02 | 0·14 | 0·27 | 2·06 | 77·78 |
| Feb. 5 | ,, | 1·35 | 18·70 | 0·41 | 0·49 | 0·12 | 1·86 | 77·07 |
| ,, 12 | ,, | 0·67 | 17·25 | 0·04 | 0·09 | 0·09 | 4·85 | 77·00 |
| ,, 26 | ,, | 1·00 | 18·80 | 0·60 | 0·40 | 0·15 | 1·65 | 77·40 |
| Mar. 20 | ,, | 0·91 | 18·65 | 0·25 | 0·23 | 0·05 | 1·79 | 78·12 |
| Apl. 24 | ,, | 0·18 | 11·60 | — | — | — | 9·80 | 78·42 |
| May 4 | ,, | 0·50 | 15·40 | 0·18 | 0·09 | 0·04 | 4·92 | 78·87 |
| ,, 26 | ,, | 0·25 | 9·55 | — | — | — | 10·55 | 79·65 |
| ,, 29 | ,, | 0·25 | 9·67 | — | — | — | 11·14 | 78·94 |
| June 1 | ,, | 0·18 | 10·50 | Trace | 0·18 | 0·08 | 10·10 | 78·96 |
| ,, 26 | ,, | 0·22 | 9·60 | 0·08 | 0·03 | 0·04 | 13·49 | 78·54 |
| July 24 | ,, | 0·35 | 14·23 | 0·35 | 0·10 | 0·01 | 6·13 | 78·82 |
| Aug. 17 | ,, | 0·10 | 15·88 | 0·67 | 0·28 | 0·08 | 5·08 | 77·91 |

The President (Mr. Leonard R. Fletcher), in moving a vote of thanks to Mr. Evans, said that the author had described the experiment as a partial failure; but often there was nearly as much to be learnt from a failure as from a success, and, at any rate, he had given the members the benefit of a most interesting experience.

Mr. J. Drummond Paton (Manchester), in seconding the motion, asked whether the author had made any experiment

on the extinction of fires by passing the inert gases through the affected area. Mr. Evans had asserted that the main extinction effect was due to the absorption of heat by the inert gas, but had referred to the specific absorption capacities of some of the gases used and the difficulty of producing large quantities. Would it be possible, so far as conditions would permit, to pass a continuous current through the affected zone? The gas, as it travelled through this area, would extinguish the fire, and maintain an extinctive atmosphere, and the resulting gases, after cooling, could be re-used. What was the actual relation between the gas sent into the zone, and the amount actually lost and circulated through fissures in the strata, etc. At what pressure was the gas sent in? He presumed that the amount of gas passed in really represented the total amount of gas which escaped through the fissures, and through other leakages.

With reference to some of the points on the temperature curve, where extreme rises were observed, he would like to call Mr. Evans's attention to the radiant energy evolved from various gases. The production of hydrogen, or similar gases, in so far as their radiant effect was concerned, was very small. There was an enormous evolution of radiant energy in the conversion of carbon monoxide into carbon dioxide, and possibly if the production of gases in conjunction with the time of maximum temperature were observed, it might be seen that at this point a high temperature was very much in evidence. As doubtless radiation was one of the main means by which the fire was transmitted to other zones, it was interesting to consider what was the actual nature of the gases that were inside the zones at the time of maximum rise.

Mr. A. J. A. Orchard (St. Helens) asked why the author should designate 140° Fahr. as "a significant temperature," and whether the winding of coal was proceeding while the experiments were being carried out. There might possibly be a connexion between the movement of the cages in the shaft and the "breathing action" referred to by Mr. Evans.

Mr. E. C. Evans (Treforest) replied that the temperature of 140° Fahr. was significant, because Fayol, in his researches on the spontaneous combustion of coal, had obtained that temperature continuously in the centre of heaps of coal of varying size

that had fired by spontaneous combustion. Fayol noticed that the coal would not fire if the heaps were below a certain size; but, as they grew larger, they began to smoke, after about three months, while the temperature in the interior of the heaps rose to about 140° Fahr. With regard to the question as to winding, the east side of the colliery was untouched by the explosion; the downcast was therefore being used for the winding of coal, whilst the upcast was used intermittently for the passage of men.

Mr. A. Ross (Manchester) asked whether the samples of air submitted to analysis were always taken at the same place. His experience on several occasions was that a sample might be taken from one particular spot and found, upon analysis, to be quite different from a second sample taken about a foot away. In matters of that kind it was very important that the samples should be taken at exactly the same spot each time.

Mr. Evans said that the samples, except, perhaps, those from the Klondyke district, were always taken at the same place. Where the analyses gave indications of imperfect samples, a further sample was taken—generally by himself—as soon as possible afterwards. The figures given in the paper, with one or two exceptions, which were noted, could be taken as a fairly accurate indication of the conditions prevailing at Senghenydd.

Mr. John Gerrard (Worsley) asked whether the failure of the application of carbon dioxide was due to the fact that a considerable amount of air had access to the fire.

Mr. Evans replied that this essentially was the case.

Mr. Gerrard said that the lesson to be learnt from this was that, unless the supply of air could be cut off, the injection of carbon dioxide was ineffective. The application of carbon dioxide in connexion with an underground fire in Lancashire in 1849 was recorded in the Report of the Accidents in Mines Commission for 1852, wherein it was stated that Mr. James Darlington had dealt successfully with a fire in the Worsley Four-Foot Seam, and had completely extinguished it by the use of that gas. The plan that he followed was to seal up the two shafts, thus cutting of all access of air. With regard to the Senghenydd experiment, it was obvious that the failure, during the long period of

trial from October to August, was due to the free access of air, which had the effect of feeding the fire.

Mr. EVANS agreed that the continued combustion was due to the leakage of air, but, on the other hand, he had no hesitation in stating that the carbon dioxide did ultimately extinguish the fire. Their difficulty lay in reducing the temperature. Apart from the small amount of heat absorbed by the carbon dioxide injected, the only factor that tended to reduce the temperature was the conduction that took place through the strata. Under the prevailing conditions the strata would have retained their heat possibly for a number of years, and at the end of that time would still have been in a state to burst into active combustion immediately the bashings or stoppings were reopened. Inability to reduce the temperature was the reason for the failure, and not so much the air-leakage. They had overcome the fluctuations due to breathing, to changes of atmospheric temperature, and to changes of barometric pressure, but could not reduce the temperature.

Mr. GERRARD said he gathered that the fire had been extinguished several times, but had broken out again. This point required some explanation. If the fire was actually extinguished by the application of carbon dioxide, why was it stated that "it was water and perseverance that put the fire out?"

Mr. H. STEPHENSON (Tyldesley) said that he had had experience of fires in mines, and had been told that it was wrong to extinguish them by means of water and filling out, rather than by sealing off. He always felt, however, that if the strata were fractured (as was the case apparently at Senghenydd) for many yards above the seam where the fire was burning, it was practically impossible to extinguish it by means of carbon dioxide, or any other gas, unless the gas could be directed to the actual seat of the fire. He was inclined to think that the cause of the failure at Senghenydd was the presence of too many fissures, which prevented the gas from being sent to the exact spot at which it was required.

The further discussion of the paper was adjourned.

## DISCUSSION OF MR. DAVID E. THOMAS'S PAPER ON "THE VALUE OF THE EXPERIMENTAL FAN IN THE MINING LABORATORY."*

Mr. DAVID E. THOMAS (St Helens) wrote that several valuable suggestions had been made in the previous discussion. Mr. Williams had raised the question whether the Pitot tube recorded any pressure on the outlet side of the fan when the fan-inlet was closed. Theoretically, the reading should be zero, and in actual practice it was very small. As the fan at the Gamble Institute, St. Helens, was of the single-inlet type, a slight leakage might take place between the fan and its casing on the side remote from the fan-inlet. In a good type of fan the influence of eddies due to readmission at the discharge was absent.

While no direct criticism had been made concerning the method adopted in obtaining the maximum static water-gauge created by the fan, and adding to it the dynamic water-gauge, both Mr. Williams and Mr. Bryson had touched upon it. The reason for the selection of the discharge side for the measurements of the dynamic water-gauge rather than the inlet side, where possibly the influence of eddies was less pronounced, opened up the whole question of the method of measurement adopted. In order to ascertain the work done by a fan, both the dynamic water-gauge and the static water-gauge must be determined and added together. In the case of a fan working with its fan-inlet closed, a static water-gauge would be observed on the inlet side, but no air moving, and consequently there would be no dynamic water-gauge. If the fan-inlet were opened, and air allowed to move, then, even though the same static water-gauge was obtained, there would be also a dynamic water-gauge proportional to the velocity or volume which was being moved, and an increase in the power required to drive the fan. If a fan were working in such a position that it blew direct to the atmosphere as an exhaust fan, there was always a loss of energy generated by the fan equal to the dynamic head at the fan-outlet. This was always minimized as far as possible by the introduction of the "évasée" outlet. If the "évasée" outlet was properly designed to suit the conditions, then the gradual reduction of the velocity was converted into useful work on

* *Trans. Inst. M. E.*, 1916, vol. l., page 482.

the inlet side of the fan. For reasons already stated, the fan at the Gamble Institute did not possess an "évasée" outlet.

The writer hoped that the foregoing remarks would serve to show that the dynamic head or water-gauge must be measured on the exhaust or outlet side. True, if only velocity of air-current was required, the dynamic water-gauge could be taken at any selected point on the inlet side where the influence of eddies was found to be least.

With reference to the observations submitted by Mr. Williams on the Sirocco fan at Manchester University, the apparent disagreement of the results with those submitted by the writer in Tables III., IV., and V. were due, in all probability, to the fact that the minimum "opening" used was 0·4 square feet. That particular fan was smaller than the one at the Gamble Institute. On reference to Table III. it would be noted that when the area of "opening" used was 0·6 square foot, the observed static water-gauge was less than that observed with a "closed inlet." If plates with "openings" of 0·1, 0·2, and 0·3 square foot respectively were used by Mr. Williams on his fan, it was quite possible that results similar to those obtained at St. Helens would be produced.

A number of suggestions had been put forward in explanation of the apparent discrepancy between the results submitted in Tables III., IV., and V., and the hitherto generally accepted theory that when the fan-inlet was completely closed the depression observed was the greatest at that speed of the fan. He was of opinion that this depended largely on the particular characteristics of the make of fan, and the particular shape and angle of the blades: these varied considerably in different types of fans. The various suggestions offered were of real value, and afforded lines of investigation for further experimental work. Any explanation based on theoretical considerations alone was insufficient, and it was to be hoped that experimental investigations of such considerations might lead to a definite solution of the difficulty. Undoubtedly, the statement made by one of the speakers, that neglect of experimental investigation of theoretical conclusions in the past had resulted in the promulgation of false theories in some text-books, contained more than an atom of truth. The danger was one which could easily be avoided by a combination of theoretical and experimental investigations. It had not, perhaps, been made clear enough in

the paper that the use of the Pitot tube and the determination of the dynamic water-gauge had only been attempted in the experiments on the fan at the Gamble Institute. The experiments on the larger colliery fans were carried out solely for the purpose of confirming the results (submitted in Table III.) obtained with the experimental fan. Mr. Bryson had quoted a statement from Mr. G. L. Kerr's *Practical Coal-mining*, that "the velocity of the air passing through a mine is proportional to the square root of the water-gauge, was a law which was only approximately true except at very high velocities." It was not the only book which contained such statements. Prof. R. A. S. Redmayne in *Modern Practice in Mining* (Vol. IV., page 59) expressed the view that the ventilating pressure increased as the 1·75th power of the volume. The figures submitted in Table I. of his (the writer's) paper did not confirm such views. The addition of the dynamic water-gauge to the static water-gauge did not affect the figures in Table I., and the volume would be found on plotting against the square root of the static water-gauge to vary as the square root of the static water-gauge. It was interesting to note that Mr. Bryson's conclusions with reference to the value of "the coefficient of the *vena contracta*" were in close agreement with the value submitted in the paper.

Reference had been made to the need for standardization in the method of carrying out tests on fans. It was highly necessary, and some organized steps should be taken as soon as possible to effect such standardization. Statements were made continually in mining journals with reference to the correct position of the water-gauge, each person claiming that his method of placing the water-gauge was correct, but carefully avoiding to state clearly the grounds for such an assumption. The suggestions made by Mr. Williams that a committee of The Institution of Mining Engineers should, in conjunction with the Government, make use of the Eskmeals Experimental Station for the purpose of testing fans was most timely and very valuable, particularly in view of the encouraging attitude of the Government in their scheme for the organization and development of scientific and industrial research. Such a commttee would investigate at the outset the best method of carrying out fan tests, and such a method might then form a basis to which all fan tests might be standardized.

In conclusion, he expressed the hope that the paper had sufficiently demonstrated the value of an experimental mine fan in a Mining School. The number of Mining Schools and Colleges in this country that had been in existence for a number of years, but had not yet a fan equipment in their laboratories, was surprising, and only served to emphasize the reason why that branch of mining engineering had been so barren of increased knowledge during recent years.

## DISCUSSION OF DR. GEORGE HICKLING'S PAPER ON "THE GEOLOGICAL STRUCTURE OF THE SOUTH LANCASHIRE COALFIELD."*

Mr. ALEXANDER FAULDS (Vancouver, B.C.) wrote that the author had not given any data, in the shape of the number, thickness, and quality of the workable coal-seams, whereby one could estimate the worth of the coalfield, after neglecting the dips. Sir Thomas Holland had stated that the coalfield might be roughly estimated as worth some £5,000,000 sterling per square mile. This was equivalent to £7,812 10s. per imperial acre, which was a very high value indeed, but was probably due to the fact that the field contained valuable coal-seams which would be worked with reasonable royalties, at moderate depths, and according to the accessibility of the coalfield to lines of transportation.

In British Columbia and the United States of America the value of coal lands consistent with favourable transportation facilities was appraised at ½d. (1 cent) per ton for lignite, 1d. (2 cents) per ton for bituminous, and 1½d. (3 cents) per ton for anthracite or cannel coals per acre of 1,000 tons per foot thick. This gave a roughly estimated worth of £64 per acre, or £40,960 per square mile for three seams 7, 4, and 5 feet thick respectively, or a total thickness of 16 feet of good bituminous coal of coking quality. This was the price paid in 1865 for several hundred acres near Nanaimo, Vancouver Island. The coalfields of this island were of the Cretaceous Period. Some of the Pennsylvanian coalfields were worth £80 per acre-foot, and belonged to the Carboniferous Period.

* *Trans. Inst. M. E.*, 1915, vol. l., page 328; and 1916, vol. li., page 91.

# THE NORTH STAFFORDSHIRE INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,
HELD AT THE CENTRAL SCHOOL OF SCIENCE AND TECHNOLOGY, STOKE-ON-TRENT,
MARCH 27TH, 1916.

MR. JOHN GREGORY, PRESIDENT, IN THE CHAIR.

The SECRETARY read the minutes of the last meeting, which were confirmed and signed.

The following gentleman was elected:—

MEMBER—

Mr. JOHN BRUCE HARDING, Biddulph Valley Ironworks, Stoke-on-Trent.

Mr. W. SIMONS read the following paper:—

## NOTES ON THE SPECIFICATION OF IRON AND STEEL SUITABLE FOR COLLIERY USE.

BY W. SIMONS.

*Introduction.*—It has been suggested to the writer that a short paper, describing the most suitable material, and the qualities that should be specified for the various requirements of a colliery, may be of interest to the members. As large quantities of iron and steel are used in modern collieries, a serious responsibility rests with the manager to see that material of good quality is used, and unless such care is exercised, loss of life and serious loss to the company may result. The object of this paper, therefore, is to describe the standards of quality that should be specified in ordering material ordinarily required for colliery use, and also the qualities most suitable for particular purposes.

There are three well-known classes of material in general use, namely, wrought-iron, open-hearth steel, and Bessemer steel, but the last two are subdivided into the acid and basic processes respectively. Doubtless the terms "acid open-hearth steel," "acid Bessemer steel," "basic open-hearth steel," and "basic Bessemer steel," are quite familiar. It does not come within the scope of this paper to describe in detail the processes of the manufacture of the several materials referred to, excepting so far as it is necessary to explain the meaning of the terms "wrought-iron," "acid," "basic," etc.

The manufacture of wrought-iron can be traced back to a very ancient period, but it was in 1784 that Henry Cort first patented the furnace which enabled wrought-iron to be produced on a commercial scale. To him belongs the credit of inventing the process for refining cast-iron by the direct use of coal in a reverberatory or air-furnace, which was afterwards known as the "puddling process." The iron is first refined in the puddling-furnaces in small quantities, by melting down the mixtures, or various grades of pig-iron, thus eliminating by oxidation the carbon, silicon, and manganese entirely, and partly removing the phosphorus. The purified iron cannot be melted at the temperature obtainable in a puddling-furnace; the whole assumes a pasty condition, composed of pure iron surrounded by a quantity of iron oxide, or what is commonly termed "slag." The iron is worked up into balls of convenient size, hammered to squeeze out as much as possible of the contained slag, rolled into puddled bars, which are afterwards piled and reheated, and rolled sometimes two or three times, according to the quality required, in order to squeeze out still further the contained slag. During this process the individual grains or crystals are rolled out into long fibres, each fibre being coated with a microscopically thin film of slag. This imparts to the iron its fibrous texture, and doubtless this covering of slag gives greater resistance to corrosion in wrought-iron.

It is difficult, on account of the similarity of the physical properties of both iron and steel, to define the two classes of metals satisfactorily. It will be noted, however, that wrought-iron is not produced in liquid or in molten form. The iron in the puddling-furnace is worked up from a pasty condition into balls, whereas steel on the other hand is produced in a liquid

form in large masses up to 100 tons per charge, and is therefore more economical to manufacture. Dr. Greiner defined wrought-iron as being "non-molten and malleable," cast-iron as "molten and non-malleable," and steel as "molten and malleable."

The acid Bessemer and acid open-hearth methods were the earliest for the commercial production of steel, but these processes require the purest hæmatite ores, free from sulphur and phosphorus, which are the principal deleterious elements in iron and steel, and cannot be eliminated during the process. Excess of sulphur makes the steel "red short," or difficult to manipulate or roll when hot, and excess of phosphorus makes the steel brittle and dangerous to use when cold. The ores for the production of hæmatite pig-iron to be used in the acid processes are chiefly obtained from Cumberland and Spain.

The Bessemer process is a very rapid one. A charge of 10 to 20 tons of molten pig-iron is poured into a converter mounted on trunnions; it supplies its own heat from chemical reaction between the oyygen of the air, which is blown through the bath of metal at a pressure of 25 pounds per square inch, and the carbon, silicon, and manganese contained in the iron. At the commencement of the blow, a small flame issues from the mouth of the converter, which, as the oxidation of these elements proceeds, increases in volume; the completion of the process is indicated by the flame suddenly dropping, the process of conversion only occupying from 15 to 20 minutes. The manufacture of steel of any desired quality is not under such control in a rapid method like this as it is in the open-hearth furnaces, and it is significant that, although Bessemer steel was largely used, it is now being replaced by open-hearth steel; in fact, the writer is not aware of any additional or any entirely new plants having been put down in this country within the last ten years.

The open-hearth furnace is a rectangular structure lined with refractory material, and the capacity is usually from 25 to 100 tons. The process is slower, a charge taking from 8 to 12 hours, but the conversion from iron to steel is much more under control; steels of varying qualities, from dead soft to high carbon, can be manufactured, and the quality is undoubtedly superior to that of Bessemer steel. In both cases the

chemistry of the process is the same; the oxygen for removing the impurities of the carbon, silicon, and manganese is supplied by the addition of iron-ore, in which the oxygen is present as oxide of iron, a combination in certain proportions of oxygen and iron. Heat is supplied to the open-hearth furnace by producer-gas, which, together with the air necessary for combustion, is pre-heated, thus enabling a very high temperature to be obtained in the furnace.

It was the invention of Thomas & Gilchrist, which enabled the phosphorus to be removed from the bath of molten metal, that gave the greatest impetus to the steel-trade, and by this invention the phosphoric ores in this country, such as the North Staffordshire Mine, Tap and Flue Cinder, Northampton, and Cleveland ores, and huge deposits on the Continent, all became available for the manufacture of steel.

The essential difference between the acid and basic processes is that, whereas in the former the converter and open-hearth furnace are lined with an acid material (sand), in the latter basic materials, such as dolomite, magnesite, etc., are employed, and lime is added to remove the sulphur and phosphorus.

Lime naturally cannot be added in the acid process. The reason is that at a high temperature the silica of the lining would combine with the lime, forming a fusible slag, thus destroying the lining, and one of the initial difficulties with the basic process was to find a lining that would enable lime to be added for the removal of the sulphur and phosphorus. In the acid process phosphorus is not eliminated, and it is therefore necessary for the production of acid steel low in phosphorus that the purest raw material, such as is obtained from the smelting of Cumberland ores, should be used. But it is becoming increasingly difficult to obtain pure hæmatite ores, and very large quantities of acid steel are now being manufactured from Spanish ores, such steel being sensibly higher in phosphorus than basic steel, which, in regard to chemical analysis will not meet the rigid specifications required by engineers, whereas basic steel fully meets such requirements.

Doubtless the best quality of acid steel ranks as the first quality of commercial steel, but it is expensive and reserved for special work, such as guns, heavy marine shafting machinery, axles, tyres, crankshafts for winding and similar engines,

and similar requirements calling for the highest quality. It must not, however, be assumed that all acid steel is superior to basic steel, owing to the pure ores being more difficult to obtain, and, as evidence of this, large quantities of shell steel are being made from basic steel, whilst some makers of acid steel are unable to undertake the manufacture of shell steel, owing to the higher phosphorus content of their acid steel.

*Uses of Iron and Steel in Colliery Work.*—The method of manufacture of iron and steel having been touched upon, the writer will now proceed to discuss their use in practical colliery work. The requirements of iron and steel used in a colliery may be roughly placed under the following headings:—

(1) Resistance to the stresses of shock or vibration producing an alteration in the molecular structure, such as haulage couplings, pit-tubs, drawbars, etc.

(2) Chains for cage attachment.

(3) Suitable material for pit-tub bodies, pit-tub wheels and axles, and for structural work, such as pit-head framing, cages, rails for surface and underground, etc.

(4) Resistance to rapid corrosion.

Wire ropes are purposely excluded, as the subject is one that could be better dealt with by experts in the wire-rope industry.

The first requirement is undoubtedly of very great importance at all collieries, as any failure in the draw-gear attachments may have serious results, causing a runaway down a steep gradient, and involving possible loss of life. It is the almost invariable practice to use the best qualities of wrought-iron for all such work, since the fatigue-resisting properties of wrought-iron are generally assumed to be superior to those of soft steel, and it can be more easily welded. The manufacture of steel has in recent years considerably improved—to such an extent that engineers of British and foreign railways use large quantities of special drawbar steel for wagons and passenger coaches. It is a mistake, therefore, to assume that wrought-iron only is suitable where the material is liable to shock and vibration. The ordinary mechanical tensile, elongation, and contraction tests are of very little value as an indication of resistance of the material to shock, the best criterion being the results obtained

from such a machine as Prof. Arnold's alternating stress machine.

Another material, known as "Armco" iron (sometimes termed "ingot" iron), which is made by the ordinary open-hearth process, is very suitable for withstanding severe alternating strains. It cannot correctly be termed "wrought-iron," but is so called from the fact that it contains 99·84 per cent. of pure iron, which is purer than any other make of iron or steel known commercially, and, owing to its purity, its resistance to corrosion is equal to that of wrought-iron.

The following are the analyses and tests of the three grades of material referred to, and in the case of wrought-iron Grade "A" is the quality with which comparison is made:—

| | Carbon. | Manganese. | Sulphur. | Phosphorus. |
|---|---|---|---|---|
| Wrought-iron ... | 0·05 | 0·060 | 0·050 | 0·150 |
| Drawbar-gear steel | 0·08 to 0·10 | 0·330 | 0·036 | 0·030 |
| "Armco" iron ... | 0·025 | 0·039 | 0·024 | 0·009 |

*Mechanical Tests.*

| | Breaking-strain, in tons per square inch. | Elongation, in 8 inches. Per cent. | Contraction at point of fracture. Per cent. |
|---|---|---|---|
| Wrought-iron ... | 22·5 | 25 | 45 |
| Drawbar-gear steel | 23·5 | 30 | 50 |
| "Armco" iron ... | 19 to 20 | 35 | 65 |

*Alternating Tests.*

| | |
|---|---|
| Wrought-iron ... ... ... ... ... ... ... | 230 |
| Drawbar-gear steel ... .. ... ... ... ... ... | 359 |
| "Armco" iron ... ... ... ... ... ... ... | 322 |
| "B. B. B." Yorkshire iron ... ... ... ... ... | 230 |
| Best Swedish iron ... ... ... ... ... ... .. | 280 |

The alternate tests and impact tests have been carried out by Prof. Arnold, of Sheffield University, and the writer is indebted to him for the trouble that he has taken in making these tests.

The test-pieces were carefully prepared, in order to obtain exact figures of the relative merits of steel and wrought-iron, and, so far as it can be ascertained by tests, the relative resistance of each to shock and vibration.

In a paper read by Mr. J. E. Fletcher before the South Staffordshire Iron and Steel Institute, he made the following statement:—

"As is well-known, the effort required to force a fracture across a bar of iron containing slag-streaks is greater than the efforts which would be required to force a fracture across a material of the same kind free from slag-streaks or seams."

The writer was anxious to prove the accuracy of this statement, but the result of Prof. Arnold's tests does not agree with this conclusion. At the same time, it is, in the writer's opinion, still advisable under the conditions prevailing at collieries that the best grade of wrought-iron should be used for this work, the reasons for this view being as follows:—

(1) It is easier for the average blacksmith to tell by fracture good wrought-iron in comparison with lower grade quality, the better quality showing a silky and longer fibrous structure.

(2) The difference between soft steel and special soft cannot be determined by fracture.

(3) Ordinarily, it may be admitted that iron is easier to weld than steel.

Obviously, material required for draw-gear and similar work to withstand shock and vibration must be of the very best quality, and the result will quickly repay any small increase in price. Colliery managers still order such material by the obsolete method of "BBB," "BB," or "B," as the case may be, and probably accept the most favourable price. One firm's "BBB" may be slightly better than another's, or one can safely go further and say that one firm's "BB" is equal to another's "BBB," as no clear and defined tests are recognized, the buyer relying upon the reputation of the firm.

However satisfactory this may have been, the responsibility rests upon the colliery manager to define the quality desired, and as all quantities of wrought-iron and steel have for some years been standardized by the British Standards Committee, the buyer when ordering should in every case clearly specify the particplar grade required, as by so doing he should know to what mechanical tests the material should conform for any size. The old "BBB," "BB," and "B" qualities are now replaced by the British Standard Grades of "A," "B," and "C," and full particulars of them will be found in Tables I. to III. It should be carefully noted that Grade "A," especially in the larger sizes, is of a better quality than the average "BBB" iron. For instance, if we take a bar of iron 1¼ inches in diameter the average result that might be expected would be as follows:—

| | Tensile. | Elongation, in 8 inches. | Reduction of area. |
|---|---|---|---|
| | Tons. | Per cent. | Per cent. |
| | 21 to 24 | 25 | 40 |
| Grade "A" test for same size is as follows :— | 21 to 24 | 25 | 45 |

Grade "A," although intended as a substitution for "BBB," requires much more care in manufacture for a seemingly slight increase in the reduction of area; but the difference is important, as it represents a marked superiority. Grade "A" quality is, therefore, much more desirable for such colliery requirements. It is only necessary when ordering material to mention the grade required, "A," "B" or "C," and the manufacturer will know what tests the buyer will be entitled to obtain.

With respect to the material enumerated under the second heading, for pit-tub bodies, comprising generally small angles, flats, and in some cases plates, unless the moisture and atmosphere are of a corrosive nature, either wrought-iron or mild steel can be used for this work, and the price no doubt will be the determining factor. Untested material is quite suitable, more particularly as tested material usually carries an increased price. Reasonably good quality should be provided, even though tests are not called for.

*Pit-tub Wheels and Axles.*—These are specialities manufactured by few firms, and again the reputation of the maker is relied upon. But it is equally incumbent upon the colliery manager to specify that the wheels and axles should be of suitable hard quality. On no occasion should ordinary mild steel or wrought-iron be used for axles; the quality should be similar to that provided for by the British Standard Specification for railway axles, although for pit-tub axles it is not necessary to confine it to acid steel only. The use of soft or ordinary mild steel may result in bent axles, and thus may throw a tub off the road, or cause a breakage, which in turn may lead to a serious accident. The same quality should be used for shafts that hold safety-catches. The quality of material for axles should comply to the following requirements:—

| Tensile strength, in tons per square inch. | | Minimum elongation on 2 inches. Per cent. |
|---|---|---|
| 42 | with | 18 |
| or 48 | ,, | 15 |

It will be seen that this is a much harder and stronger quality for withstanding the bending-strains to which axles are subjected.

The foregoing remarks apply to cast-steel wheels, which, if of too soft a quality, would cause "flats" to form rapidly on the

wheel-tread, with eventual damage to the road. Cast-steel wheels should give approximately the following analysis:—

| | Per cent. |
|---|---|
| Carbon ... ... ... ... ... ... ... | 0·50 to 0·55 |
| Phosphorus ... ... ... ... ... ... | 0·05 ,, 0·06 |
| Manganese ... ... ... ... .. ... | 0·60 ,, 0·70 |
| Sulphur ... ... ... ... ... ... | 0·05 ,, 0·06 |
| Silicon ... ... ... ... ... ... ... | 0·40 ,, 0·60 |

The silicon percentage is much higher than is usually found in ordinary steel castings; it adds considerably to the wearing properties of the wheel-tread.

*Structural Work, Pit-head Framing, etc.*—These are extremely important matters, and care should be exercised that no untested material is used for work of this description. All structures of this nature are usually designed and the calculations based upon using mild steel conforming to the British Standard Specification of 28 to 32 tons tensile for open-hearth steel. Unless this quality is specified, and the provision made for inspection and testing, there may be a temptation (under the stress of keen competition) for the builder to purchase in the cheapest market, and possibly use basic Bessemer steel, which is very often softer in quality and not usually accepted for this class of work. Soft material from any process may result in buckling some of the members of the framing, which may eventually cause serious trouble. The foregoing remarks may equally apply to cages, but great care should be exercised that the lugs for chain-attachments should have an ample factor of safety, and be of such special quality of material as would be used in the case of drawbars and couplings.

With regard to the light rails for underground use, it is important to use hard steel similar in quality to the British Standard quality for heavy rails. If mild-steel quality is used—and this is not infrequent where the makers are not also the makers of heavy rails—the rails will bend between the sleepers, causing a wavy track, which results in loss of power for hauling. Much heavier rails are now used for main haulage-roads, varying from 20 to 40 pounds per yard; but in many cases the rails used are badly designed, the material in the rail not being so distributed as to give the greatest strength for the weight per yard. It is recommended

here, again, that the British Standard be adopted for the shape of the rail and for the quality of the material. Standardization as far as possible is bound to result to the advantage of the user and the manufacturer. If a buyer purchases any other than the standard section, he must either continue to purchase from one maker or have varying shapes for the same weight per yard. On the other hand, all manufacturers ought to be in a position to supply standard sections if called upon to do so. It is unnecessary for the writer to give the analyses, and tests for rails, as this information can easily be obtained from the British Engineering Standard Committee, or from any manufacturer.

*Chains for Cage-attachments.*—Colliery managers are fully alive to the importance of obtaining the best quality that can possibly be obtained for this purpose, notwithstanding that it is very important that the greatest care should be exercised in specification and manufacture. Mr. Wilfred Bayliss, of Messrs. Joseph Wright & Company, has kindly furnished the writer with the tests required for the iron and also for the finished chain, as under:—

"Iron for such purpose should conform to the following tests:—Tensile, 22/24 tons per square inch—elongation, 25/30 per cent. in 8 inches, and 45/50 per cent. reduction in area at point of fracture. The iron should also show a thoroughly fibrous fracture, and bars of 1 inch in diameter and above should admit of bending cold through an angle of 180 degrees."

Provision having been made for the highest class of iron and the highest class of workmanship, the chains should be tested to the Admiralty proof-strain. They should afterwards be carefully examined link by link, and a certificate demanded from the makers of the chain, guaranteeing that the specified iron has been used in every link of the chain, and that the most skilled workmanship has been employed. The certificate should also specify to what strain the chain has been tested, and also the mark used for distinguishing purposes. It is further necessary that a 3-foot sample should be taken out of the chain and broken to destruction, when, the result, to be satisfactory, should not be less than 150 to 200 per cent. over the Admiralty proof-strain. After this has been done, the chains should then be joined up and retested to the proof-strain. The breaking result should also be stated on the maker's certificate.

ADMIRALTY TESTS FOR CHAINS.

$d$ = Diameter of iron in chain, in inches.

| | Close-link chain. Tons. | Stud chain. Tons. |
|---|---|---|
| Proof load in length of 15 fathoms ... ... | $12\,d^2$ | $18\,d^2$ |
| Destruction tests on three links from the chain | $24\,d^2$ | $27\,d^2$ |

The proof loads on close-link and stud chain given above correspond to a stress of about 8 tons and 11½ tons respectively in the iron.

The Board-of-Trade rules are the same as those of the Admiralty, except that in the case of stud chain the destruction load is only 40 per cent. greater than proof load on 2-inch sizes and over, as against 50 per cent. required by the Admiralty. The Admiralty overseers always expect to get destruction tests well above those stated in the specification, and investigate the possible causes closely if the breaking-tests approximate at all to the specification.

The Admiralty specify that the iron from which their chains are made shall stand the following tests:—

| | Tensile. tons per square inch. | Elongation. On 8-inch diameter. | On 4-inch diameter. |
|---|---|---|---|
| | | Per cent. | Per cent. |
| Bars up to 2¼ inches in diameter ... ... | 23 | 22 | 26 |
| ,, 2¼ to 2·$^9_{16}$ inches in diameter inclusive | 22½ | 22 | 26 |
| ,, over 2·$^9_{16}$ inches in diameter ... ... | 22 | 22 | 26 |

An important point with regard to chains is the reduced strength per square inch of the iron in the chain compared with the strength of the original bar. The tensile of, say, 22/24 tons is reduced in the chain to 18/19 tons per square inch, this reduction being due to losses in welding, coupled with the uneven strain on the chain.

Reference has already been made to the question of fatigue in iron. The effect of such fatigue, or continuous working, changes the structure from a closely fibrous to a coarsely crystalline condition, with a seriously diminished strength of chain or coupling, as the case may be. The Home Office regulations provide that all users of chains should frequently anneal the chains, in order to guard against this weakness and to prevent as far as possible any accidents. Such annealing, in order to be effective, must be carefully performed; the whole of the chain should be carefully brought to an equal temperature, bright red, not less than 850° Cent., and allowed to cool slowly, preferably in dry sand or hot

ashes; and in the case of chains for cage attachments not more than six months should be allowed to elapse before annealing. Chains may fail from many causes other than quality and workmanship, such as unequal distribution of the material in its design, or unequal load on each chain; but these are points of engineering efficiency which do not come within the scope of these remarks.

The writer has a link which illustrates the value of annealing. The two halves have been fractured in a similar manner; one shows clearly the crystalline fracture, and the other that the original fibrous structure has been restored by annealing.

*Corrosion.*—In conclusion the writer would like to refer briefly to the question of the relative corrosion of iron and steel. This is a highly controversial subject, but there are two theories generally accepted as causes of the corrosion of iron and steel. One is the acid theory, advocated by Calvert in 1871, who found corrosion due to an acid moisture, and the other the electrolytic theory, the corrosion being generally caused by ordinary atmospheric influence, where the presence of acid is not necessary to effect the rusting of iron. Water is assumed to be an electrolyte —that is to say, a small proportion of its molecules are ionized, and iron passes into solution with consequent precipitation of a further quantity of rust and so on.

Under ordinary atmospheric conditions wrought-iron doubtless is a material that will withstand corrosion better than ordinary mild steel, but at this point it may be said that the softer and purer the steel is the better it will withstand corrosion.

"Armco" iron, with its almost absolute purity, naturally stands high in this respect, and so far as the Shelton Iron, Steel, & Coal Company's experiments and those of Dr. Stead have gone, it may be said to be quite equal to wrought-iron. In the case of a damp acid atmosphere, or acid moisture of any description, there is very little doubt that soft steel and "Armco" iron are quite equal to wrought-iron.

There are doubtless many collieries where corrosion is chiefly due to acid. If the colliery be wet, the acid may come from several causes, namely: (*a*) natural acid reaction of the water; or (*b*) acid or metallic salt reaction, due to oxidation of the sulphur in the coal. A typical case is that of the Woodhead Tunnel on the

Great Central Railway; water is continually percolating through and takes up the sulphur from the smoke of the engines, forming sulphurous and sulphuric acid, which drops on the rails and causes corrosion to such an extent that the rails have to be very frequently renewed. In damp pits the fine coal-dust becomes wet, clings to all iron surfaces, and the sulphur readily oxidizes and causes rapid corrosion.

The above conclusions have been arrived at from laboratory experiments in testing various metals, but colliery managers are in a position to help forward the solution of the problem. It would be of the greatest value, therefore, if at any colliery in which such conditions obtain samples of wrought-iron, steel, and "Armco" iron could be tried side by side, and careful notes taken of the results. Ordinary laboratory experiments on this point are not so conclusive as a practical test, since it is all but impossible to reproduce conditions prevailing in general practice.

In concluding, the writer would like to acknowledge the assistance received from Mr. W. J. Brooke in preparing the tests recorded, and in connexion with the conclusions on corrosion experiments carried out by him.

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The PRESIDENT (Mr. John Gregory) said that the paper would be of great assistance to managers and engineers of collieries. All collieries were large users of both iron and steel, but it was questionable whether many managers had the time to study closely the composition and properties of either material, or to specify closely the exact grades most suitable for their special requirements. When one spoke of "steel," it had to be borne in mind that the term covered an infinite variety of material ranging from the hair-spring of a watch to the heaviest castings used in modern machinery or constructional work. They were indebted to Mr. Simons for giving them a clear insight into the properties of the various classes of steel to which he had referred. Mr. Simons was probably well advised in leaving out the consideration of wire ropes in a paper which dealt with iron and steel generally, for although rope was one of the most important uses to which steel was put at a colliery, it was quite a special subject. He

TABLE I.—BRITISH STANDARD TESTS FOR WROUGHT-IRON.—GRADE A.

| Section. | Dimensions. | Tensile strength per square inch. | Minimum elongation. | | | | Minimum contraction of area of original area. |
|---|---|---|---|---|---|---|---|
| | | | Test-piece "B." | | Test-piece "F." | | |
| | | | As rolled. | Turned down. | As rolled. | Turned down. | |
| | Diameters or sides up to. Inches. | Tons (2,240 lbs.). | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Rounds and squares. | $\frac{3}{8}$ | 21 to 25 | 25 | — | — | — | 50 |
| | $\frac{5}{16}$ | 21 ,, 25 | 25 | — | — | — | 50 |
| | $\frac{3}{4}$ | 21 ,, 25 | 28 | — | — | — | 48 |
| | 1 | 21 ,, 25 | 28 | 25 | — | — | 47 |
| | $1\frac{1}{4}$ | 21 ,, 24 | 28 | 25 | 35 | 33 | 46 |
| | $1\frac{1}{2}$ | 21 ,, 24 | 28 | 25 | 34 | 32 | 46 |
| | 2 | 21 ,, 24 | — | 24 | — | 31 | 43 |
| | $2\frac{1}{2}$ | 20 ,, 24 | — | 23 | — | 28 | 42 |
| | 3 | 20 ,, 24 | — | 22 | — | 26 | 41 |
| | $3\frac{1}{2}$ | 20 ,, 24 | — | 21 | — | 25 | 40 |
| | 4 | 20 ,, 24 | — | 20 | — | 24 | 38 |
| | | | Test-piece "A." | | | | |
| Flats. | | Tons. | Per cent. | | | | Per cent. |
| | 4 inches wide and under, tested as rolled or machined to $1\frac{1}{2}$ inches wide by under $\frac{5}{16}$ inch thick ... | 21 to 24 | 22 | | | | 36 |
| | Do. by $\frac{5}{16}$ inch to under $\frac{1}{2}$ inch thick | 21 ,, 24 | 23 | | | | 38 |
| | Do. by $\frac{1}{2}$ inch thick and over up to 1 inch thick inclusive ... ... | 21 ,, 24 | 24 | | | | 40 |
| | Over 4 inches wide, tested as rolled or machined to $1\frac{1}{2}$ inches wide by $\frac{1}{2}$ inch thick and under ... ... | 21 ,, 24 | 22 | | | | 36 |
| | Do. by over $\frac{1}{2}$ inch thick up to and including 1 inch thick ... ... | 21 ,, 24 | 23 | | | | 38 |
| Angles, tees, and channels. | $\frac{1}{2}$ inch thick and under ... ... | 21 to 24 | 18 | | | | 27 |
| | Over $\frac{1}{2}$ inch thick | 21 ,, 24 | 20 | | | | 29 |

NOTE. — Flats over 1 inch thick shall comply with the tests applicable to a square bar having a side equal to the mean of the two adjacent sides of the flat.

TABLE II.—BRITISH STANDARD TESTS FOR WROUGHT-IRON.—GRADE B.

| Section. | Dimensions. | Tensile strength per square inch. | Minimum elongation. | | | | Minimum contraction of area of original area. |
|---|---|---|---|---|---|---|---|
| | | | Test-piece "B" | | Test-piece "F." | | |
| | | | As rolled. | Turned down. | As rolled. | Turned down. | |
| | Diameter or sides up to. Inches. | Tons (2,240 lbs.). | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Rounds and squares. | $\frac{3}{8}$ | 21 to 25 | 22 | — | — | — | 40 |
| | $\frac{5}{8}$ | 21 ,, 25 | 22 | — | — | — | 40 |
| | $\frac{3}{4}$ | 21 ,, 25 | 25 | — | — | — | 40 |
| | 1 | 21 ,, 25 | 25 | 22 | — | — | 38 |
| | $1\frac{1}{4}$ | 21 ,, 25 | 25 | 22 | 31 | 27 | 38 |
| | $1\frac{1}{2}$ | 21 ,, 25 | 24 | 22 | 30 | 26 | 36 |
| | 2 | 21 ,, 25 | — | 21 | — | 25 | 36 |
| | $2\frac{1}{2}$ | 20 ,, 24 | — | 20 | — | 24 | 36 |
| | 3 | 20 ,, 24 | — | 19 | — | 23 | 34 |
| | $3\frac{1}{2}$ | 20 ,, 24 | — | 18 | — | 22 | 34 |
| | 4 | 20 ,, 24 | — | 17 | — | 21 | 32 |
| | | | Test-piece "A." | | | | |
| | | Tons. | Per cent. | | | | Per cent. |
| Flats. | 4 inches wide and under, tested as rolled or machined to $1\frac{1}{2}$ inches wide by under $\frac{5}{16}$ inch thick ... | 21 to 24 | 18 | | | | 27 |
| | Do. by $\frac{5}{16}$ inch to under $\frac{1}{2}$ inch thick | 21 ,, 24 | 19 | | | | 29 |
| | Do. by $\frac{1}{2}$ inch thick and over up to 1 inch thick inclusive ... ... | 21 ,, 24 | 20 | | | | 31 |
| | Over 4 inches wide, tested as rolled or machined to $1\frac{1}{2}$ inches wide by $\frac{1}{2}$ inch thick and under ... | 21 ,, 24 | 18 | | | | 27 |
| | Do. by over $\frac{1}{2}$ inch thick up to and including 1 inch thick ... ... | 21 ,, 24 | 19 | | | | 29 |
| Angles, tees, and channels. | $\frac{1}{2}$ inch thick and under ... ... | 21 ,, 24 | 15 | | | | 22 |
| | Over $\frac{1}{2}$ inch thick | 21 ,, 24 | 17 | | | | 24 |
| Plates. With the grain. | $\frac{1}{4}$ inch to $\frac{5}{8}$ inch thick ... ... | 20 ,, 24 | 12 | | | | — |
| | $\frac{3}{4}$ inch to $\frac{7}{8}$ inch thick ... ... | 20 ,, 24 | 10 | | | | — |
| Across the grain. | $\frac{1}{4}$ inch to $\frac{5}{8}$ inch thick ... ... | 17 ,, 21 | 4 | | | | — |
| | $\frac{3}{4}$ inch to $\frac{7}{8}$ inch thick ... ... | 17 ,, 21 | 4 | | | | — |

NOTE. — Flats over 1 inch thick shall comply with the tests applicable to a square bar having a side equal to the mean of the two adjacent sides of the flat.

TABLE III.—BRITISH STANDARD TESTS FOR WROUGHT-IRON.—GRADE C.

| Section. | Dimensions. | Tensile strength per square inch. | Minimum elongation. | | | |
|---|---|---|---|---|---|---|
| | | | Test-piece "B." | | Test-piece "F." | |
| | | | As rolled. | Turned down. | As rolled. | Turned down. |
| | Diameters or sides up to. Inches. | Tons (2,240 lbs.). | Per cent. | Per cent. | Per cent. | Per cent. |
| Rounds and squares. | $\frac{3}{4}$ | 21 to 25 | 18 | — | — | — |
| | $\frac{9}{16}$ | 21 ,, 25 | 18 | — | — | — |
| | $\frac{3}{4}$ | 21 ,, 25 | 22 | — | — | — |
| | 1 | 21 ,, 25 | 22 | 19 | — | — |
| | $1\frac{1}{4}$ | 21 ,, 25 | 22 | 19 | 26 | 23 |
| | $1\frac{1}{2}$ | 21 ,, 25 | 21 | 18 | 25 | 22 |
| | 2 | 21 ,, 25 | — | 17 | — | 21 |
| | $2\frac{1}{2}$ | 20 ,, 24 | — | 16 | — | 20 |
| | 3 | 20 ,, 24 | — | 15 | — | 19 |
| | $3\frac{1}{2}$ | 20 ,, 24 | — | 14 | — | 17 |
| | 4 | 20 ,, 24 | — | 13 | — | 15 |
| | | | Test-piece "A." | | | |
| Flats. NOTE. — Flats over 1 inch thick shall comply with the tests applicable to a square bar having a side equal to the mean of the two adjacent sides of the flat. | 4 inches wide and under, tested as rolled or machined to $1\frac{1}{2}$ inches wide by under $\frac{5}{16}$ inch thick ... | Tons. 21 to 25 | Per cent. 14 | | | |
| | Do. by $\frac{5}{16}$ inch to under $\frac{1}{2}$ inch thick ... ... | 21 ,, 25 | 15 | | | |
| | Do. by $\frac{1}{2}$ inch thick and over up to 1 inch thick inclusive ... ... ... | 20 ,, 24 | 16 | | | |
| | Over 4 inches wide, tested as rolled or machined to $1\frac{1}{2}$ inches wide by $\frac{1}{4}$ inch thick and under ... | 20 ,, 24 | 14 | | | |
| | Do. by over $\frac{1}{2}$ inch thick up to and including 1 inch thick ... ... ... | 20 ,, 24 | 15 | | | |
| Angles, tees, and channels. | $\frac{1}{2}$ inch thick and under ... | 21 ,, 25 | 12 | | | |
| | Over $\frac{1}{2}$ inch thick ... ... | 20 ,, 24 | 14 | | | |
| Plates. | | | | | | |
| With the grain. | $\frac{1}{4}$ inch to $\frac{5}{16}$ inch thick .. | 20 ,, 24 | 8 | | | |
| | $\frac{3}{8}$ ,, $\frac{7}{8}$ ,, ,, ... | 20 ,, 24 | 8 | | | |
| Across the grain. | $\frac{1}{4}$ ,, $\frac{5}{16}$ ,, ,, ... | 17 ,, 21 | 3 | | | |
| | $\frac{3}{8}$ ,, $\frac{7}{8}$ ,, ,, ... | 17 ,, 21 | 3 | | | |

hoped, therefore, that they might prevail upon some member closely in touch with the manufacture of ropes to give the Institute the benefit of his knowledge by contributing a paper on the subject. He (Mr. Gregory) was interested to note that, in giving the alternating test for various materials, Mr. Simons had included the figures for "Armco" iron. The name of this material might not be familiar to all of them, but he believed that he was right in stating that this was the product of a new method of iron manufacture, which had been adopted exclusively in this country by the Shelton Iron, Steel, & Coal Company, Limited. The material possessed some remarkable properties, and he was greatly interested in experiments which were being made in its application to mining requirements. With regard to the specification of wrought-iron, he must personally plead guilty to Mr. Simons's indictment that colliery managers ordered "B" or "BBB" iron without knowing exactly what tests were indicated by such a classification. The British Standard grades "A," "B," and "C," however, afforded a reliable indication of quality, and their adoption would secure uniformity where tenders from various makers were under consideration. He strongly commended the statement of Mr. Simons that "standardization as far as possible is bound to result to the advantage of the user and the manufacturer," and this applied not only to bar-iron and steel, but to every piece of apparatus or material used in the working of collieries. He was interested in Mr. Simons's remarks on the relative liability of iron and steel to corrosion. In many instances—wagon bottom-plates, for example—this was of great importance, and he hoped that some of the members would record their experiences in this connexion.

Prof. JOHN CADMAN (Birmingham University) said that the paper was one of considerable value, being full of very suggestive and useful information. There was a great deal that could be said upon the subject, and two points seemed especially worthy of note. In the first place, the paper, so far as he could recollect, was the first to appear in the *Transactions* on this important subject. The Institution was, therefore, to be congratulated on receiving from a man of the author's experience first-hand information. Secondly, the paper was a record of very valuable research-work of special application to colliery practice. As a

general rule, if one tried to obtain information on materials of this character, one was confined to tests for material used in some particular branch frequently foreign to that in which one was interested. In this case research had been conducted specially in materials used for mining purposes, and in that respect they owed Mr. Simons a debt for having taken the trouble to carry out the tests for their benefit. He was not so sure that Mr. Simons was wise to leave out the question of wire ropes. He (Prof. Cadman) would have liked Mr. Simons to deal with that subject, and by its omission he ventured to think that the Institution was the loser. Mr. Simons had called attention to the British Standards Committee, whose work he (Prof. Cadman) thought was not sufficiently known amongst colliery people. The country was suffering at the present time from lack of standardization and lack of organization, and it seemed more necessary than ever to standardize in every direction. He moved a hearty vote of thanks to Mr. Simons.

Mr. J. W. HARTLEY (Stone) endorsed the remarks of the previous speakers with regard to the thoroughly practical character of the paper. With reference to wagons, he did not believe that a strict specification for a commercial 10-ton wagon was ever given. This was usually made at the cheapest possible price, the reputation of the makers being occasionally given the preference. The buffers were frequently made of what would be called "hammered scrap," which often represented any inferior iron that could be piled, furnaced, and hammered into the shape of a buffer. The head of a buffer and broken coupling-links were often seen lying on the railway ballast. It was necessary that good material for railway-wagons should be specified and used. With regard to "Armco" iron, he would be glad to know whether it was suitable for locomotive fire-boxes. Every colliery manager was interested in obtaining an efficient substitute for copper, because of its high cost, particularly at the present time.

With reference to the cost of and varying qualities of steel in locomotive and wagon tyres, he thought that colliery engineers did not always realize the economy that resulted from using the higher and more expensive qualities. He emphasized the importance of annealing iron chains, as generally insufficient attention was given to this point. He had seen

chains in use for many years without their being annealed, and accidents caused by their breaking. He had had some experience in the use of wire ropes, but not of the larger sizes used at collieries. He recalled that in connexion with the haulage of sewage distributors Lang's-lay wire ropes $\frac{9}{16}$ inch in diameter had run successively night and day for five or six years. A rope that replaced one of these, and was constructed in the ordinary way, lasted only twelve months. With reference to the British Standard Specifications, many persons did not know that they existed, and few knew the full scope of them. He thought that it would be an advantage to a mining institute to have a *résumé* in a condensed form of these standard specifications, which should contain such extracts as would be useful to colliery requirements.

Mr. E. B. Wain (Chatterley Whitfield Collieries) said that the paper put in a scientific way what many of them had dealt with in a rule-of-thumb manner in the past. The use of iron or steel for a particular purpose was of grave importance, and one looked forward to the further development of the Shelton Company's enterprise in regard to "Armco" iron for the production of yet another material for colliery use. He would suggest that for pit-tubs, in particular, a new material would be specially valuable.

In the making of tub-bottoms, in which the iron was bent in two directions, they often met with disaster, unless iron of a very high grade was employed. Steel was very much more easily bent, but against that advantage must be set the rapid corrosion that took place in steel pit-tubs. For several years past he had used only a high quality of wrought-iron for pit-tub work, and it had paid him to do so. At the same time, colliery managers would be glad to have some new material that would give them a much more durable pit-tub.

They all regretted that Mr. Simons had not dealt with steel for wire ropes, for that was the all-important use of steel at a colliery. Some of them had tried for many years to accumulate data and analyses, in order to obtain something like a standard specification for high-class wire ropes. He had a long list of data himself, but he was sorry to say that they were so entirely contradictory that, as a non-metallurgist, he did not know what use to make of them. If Mr. Simons could help them to obtain a

standard specification for wire ropes of various stresses, it would be of the utmost possible value.

Mr. Hartley had mentioned the case of a wire rope only lasting a short time after its predecessor had been in use for six years. He (Mr. Wain) wondered whether, when the new rope was put on, the pulley was changed at the same time. If it were not, and the old rope had been working on it for six years, then when the new rope was laid on the sharp edges of the pulley, it was not surprising that it did not last longer than twelve months.

With regard to the question of purchasing a particular quality of iron, he had always been opposed to purchasing anything in the nature of common iron for colliery use: there was always the danger that it might be used for some purpose where the better quality was necessary. Taking into account the very little difference in the cost, it was far better to have a high quality for all purposes.

Mr. Simons had made a very important point with regard to the annealing of cage chains, and it needed careful thinking over. Annealing was often done in a casual sort of way, and if every colliery would include in its plant a special annealing furnace, where this work could be done on proper lines, it would be of great advantage. It was true that not many breakages occurred at collieries, but this was due to the fact that the chains used were very much stronger than was necessary, rather than on account of taking the best possible care of the chains. The present circumstances of the iron and steel trades tended to force the use of old-fashioned material at collieries. Some of them thought that they would have to resort again to wood instead of iron for tubs, and even wood in place of the steel roof supports now so largely used, unless some means could be taken to deal with the serious limitation of supply to collieries, due, of course, very largely, to the heavy demands of iron and steel for the urgent needs of the nation in other directions.

Mr. A. M. Henshaw (Talk-o'-the-Hill Colliery), in seconding the vote of thanks, said that Mr. Simons, in addition to not dealing with the subject of wire ropes, had omitted to mention tool-steel. That covered a very wide field indeed, but he hoped that he would not be asking Mr. Simons too much to include in his paper a few paragraphs dealing with it.

The vote of thanks was heartily accorded.

Mr. W. Simons (Stoke-on-Trent), after thanking the members for their appreciative remarks, said that he had felt some diffidence in stating that steel was as good as iron, lest he might be thought guilty of showing a little bias on the subject, seeing that his firm were more interested in steel than in wrought-iron; but he assured them that this fact had not influenced him in any way. He had written to Prof. Arnold of Sheffield University pointing out how astonished he was at the results obtained, because the general impression was that wrought-iron would stand fatigue better than steel. Prof. Arnold assured him, however, that the results were in accordance with previous experience in other tests. He (Mr. Simons) still thought that wrought-iron was the most satisfactory material for colliery work.

He agreed with Mr. Wain that nothing but the best material should be used at a colliery, and nothing but grade "A."

Mr. Hartley had asked whether "Armco" iron would be suitable for fire-boxes. He could only state that his firm were making one of that material, and he would be glad to let anyone know the result. His firm had been forced to do so, owing to the high cost and inaccessibility of copper. "Armco" was the purest material that could be obtained, and as near copper as iron or steel could be. With regard to tyres, the most suitable quality of steel was high-grade acid steel, made in accordance with the British Standard tests.

Certain members had regretted that he had not included the subject of wire ropes in his paper. It was an important one, as it dealt not only with the manufacture of the steel, but the method of the manufacture of the rope, and the questions of strains, acceleration, and retardation. The matter required a great amount of consideration and preparation by one who had had considerable experience with that special work, and he had thought it better, therefore, to omit it from his paper.

# THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,
HELD IN THE ROOMS OF THE SOCIETY, QUEEN'S CHAMBERS,
5, JOHN DALTON STREET, MANCHESTER,
APRIL 11TH, 1916.

MR. LEONARD R. FLETCHER, PRESIDENT, IN THE CHAIR.

The following new members were elected, having been previously nominated:—

MEMBERS—

Mr. DANIEL DARLINGTON, 212, Marlborough Street, Ashton-under-Lyne.
Mr. DAVID PRICE, Empire Colliery, Cwmgwrach, Neath.
Mr. SYDNEY RAYNER, The Marshes, Atherton Road, Hindley Green, Wigan.
Mr. JOHN P. THOMAS, 41, Graig Road, Ynishir.

## DISCUSSION OF PROF. X. STAINIER'S PAPER ON "THE CONNEXIONS BETWEEN THE NORTH-WESTERN EUROPEAN COALFIELDS."*

Mr. HERBERT BOLTON (Bristol) wrote that Prof. Stainier had rendered a notable service to British geologists in supplying so masterly an analysis of the earth-movements and accompanying physical conditions that were in operation during Carboniferous times in Northern Europe and in the British Isles. The clear determination of these broad tectonic outlines was absolutely essential if geologists were ever to advance further towards a better knowledge of the relation of one coalfield to another, and to the sequence of development of the Coal-Measures in any particular area. Prof. Stainier had shown that certain inferences as to the relationships between coalfields might be fairly reasonably drawn upon present evidence, but that more evidence was required to demonstrate those relationships as unquestionable.

* *Trans Inst. M. E.*, 1916, vol. li., page 99.

Faunal evidence had a bearing (not yet wholly recognized) upon those questions, and must be taken into account. Two examples might be quoted. The physiographical conditions of the Pendleside Period were regarded by Prof. Stainier as contradictory (page 111), inasmuch as "deep-sea" cephalopods (*Goniatites*) crowded the shales, and *Posidonomya* was no less abundant. To that assumption he (Mr. Bolton) would reply that the occurrence of all stages of *Goniatites* in the "bawn-pots" associated with the Bullion Coal in Lancashire, and the remarkable suite of nodules charged with *Goniatites* at Carre Heys, near Colne, had long ago led him to the belief that *Goniatites* were not "deep-sea" forms in Coal-Measure time, but that they had flourished in inshore waters, where truly littoral conditions prevailed. The extreme thinness of some of the marine horizons was, moreover, in contradiction with the hypothesis of "deep-sea" conditions.

Prof. Stainier had also drawn attention on page 142 to the existence of Upper Old Red Sandstone fishes in rocks in the Southall boring, which lithologically were of Lower Old Red Sandstone type. That occurrence was somewhat similar to what he (Mr. Bolton) had already described as existing in the Kent coalfield, where a Farrington fauna was associated with Pennant Grit types of rocks. In each case physiographical conditions must have furnished the factors that rendered that association possible.

Prof. Stainier's paper would do much to clarify the prevalent conception of the southern coalfields and their inter-relationships, and aid materially in future work on the subject.

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Mr. SHERWOOD HUNTER read the following paper on "Economies in Coal-washing":—

# ECONOMIES IN COAL-WASHING.

By SHERWOOD HUNTER.

Two of the most important economies in coal-washing are: (1) economy in the actual washing of the coal, and (2) a proper lay-out, with the view of reducing to a minimum the cost of labour for handling and washing the coal.

With regard to the first-mentioned economy, a guarantee is usually required for turning out a washed coal containing not more than 2 per cent. of free dirt and a resulting refuse with not more than 2 per cent. of free coal. Any plant that gives results within such guarantees can be considered economical, provided that there are no other losses during the washing process, namely, in the settlings from the tanks through which the washing water is circulated, or in the sediment in the overflow from such settling-tanks.

The general method of recovering the sediment (slurry) from the washing water is by means of an elevator, provided with perforated buckets, which dredges the slurry along with the whole of the washed fine coal from a pit, the coarser fine coal retaining in the buckets a certain portion of the slurry. Owing to the amount of surplus water picked up by each bucket, slurry will not settle on the coal-layer in the buckets, but is flushed through the drainage-holes in the bucket, and returns to the collecting pit, and in time the water thickens to such an extent that it becomes useless for washing. This thickened water, which may contain up to 30 per cent. of sediment, must be replaced by fresh water, because, even if it be led into separate tanks for drainage, the quality of the material is so poor that in most cases it does not pay for the labour entailed in recovering it.

The recovery of slurry can also be effected by means of drainage-bunkers, as illustrated in Fig. 1. The whole of the fine coal, after washing, is swilled down troughs into one of a row of hoppers, the coal settling down and the water overflowing

into settling-tanks, the sediment from which is pumped back into the hoppers. Perforated drainage pipes are placed inside the bunkers; these are fitted with taps at the bottom, which are closed whilst the hoppers are filling, and opened when the hoppers are full, thus allowing the water in the bunkers to drain away. This drainage-water is pumped along with slurry from the settling-tanks back into the coal-trough that supplies further hoppers. This system has proved more satisfactory than the

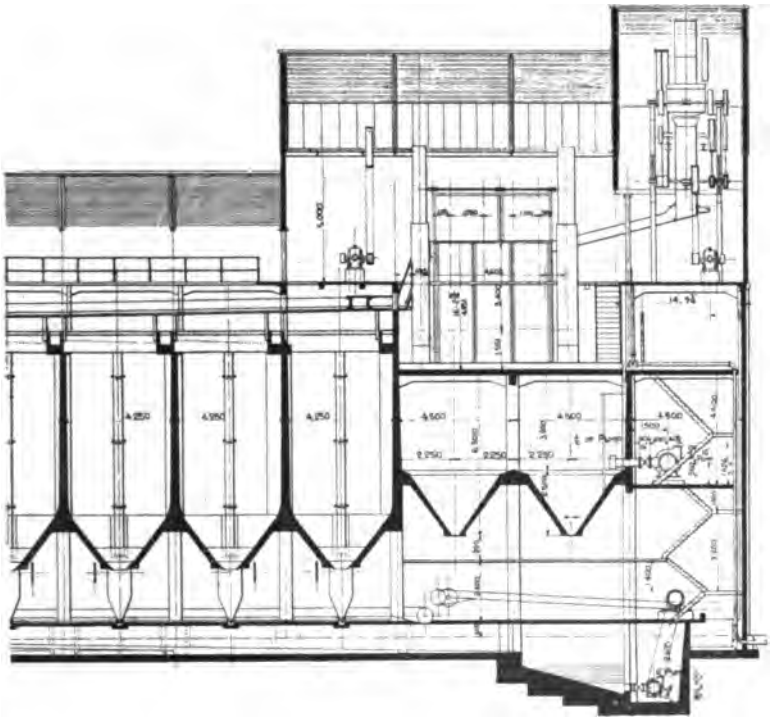

FIG. 1.—LONGITUDINAL SECTION OF OVERFLOW DRAINAGE-BUNKERS.

perforated bucket-elevator, as the flush of the water in the overflow is not so strong, and allows a greater proportion of slurry to settle amongst the coal.

Each drainage hopper is generally of a capacity of about 100 tons, and with a 100-ton-per-hour washery this would require on an average about two hours to fill.

Where the working of the plant is not continuous, or for some reason has to be stopped from time to time, a film of slurry accumulates on the top of the coal in the hoppers. This film

prevents the drainage of any further coal filled in to such hoppers on the top, so that it becomes necessary to change over into a new hopper each time that the plant has to stop, say, for want of coal, shortage of power supply, etc.

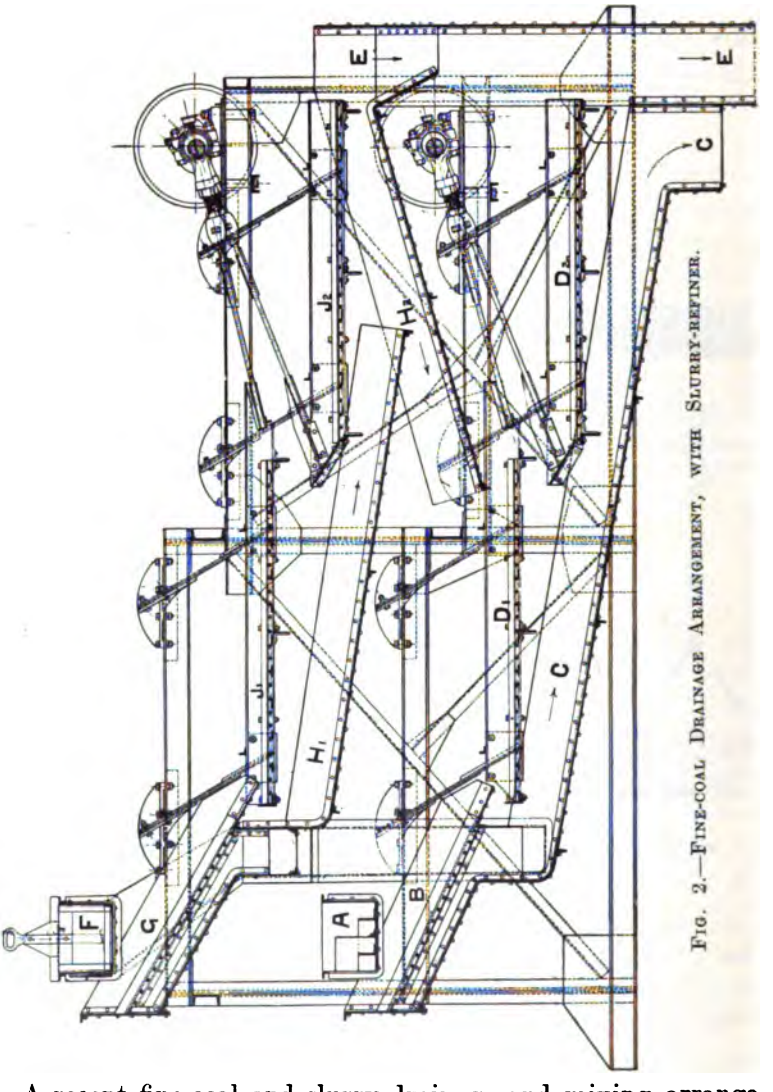


FIG. 2.—FINE-COAL DRAINAGE ARRANGEMENT, WITH SLURRY-REFINER.

A recent fine-coal and slurry drainage and mixing arrangement is illustrated in Fig. 2. The coal, after being washed, arrives along with the washing water in the distributor *A*, and flows on to the drain-sieves *B*, where the bulk of the water and

slurry is extracted, the coal being finally drained on the vibrating sieves *D*1 and *D*2. The water along with the slurry is delivered into a settling-tank; the slurry returns in trough *F*, is concentrated on sieve *G*, and is finally drained on the vibrating sieves *J*1 and *J*2. The slurry, after passing over the sieve, is then mixed with the fine coal from *D*1 and *D*2 in the shoot *E*. The drainage from the concentrating sieves *G* goes back into the settling-tank, whereas the drainage from the shakers *J*1 and *J*2 flows on to the fine coal, passing along the vibrating screen *D*1. The coal acts as a filter and retains the coal-particles; the drainage, however, runs along the water-shoot *C* to the settling-tank.

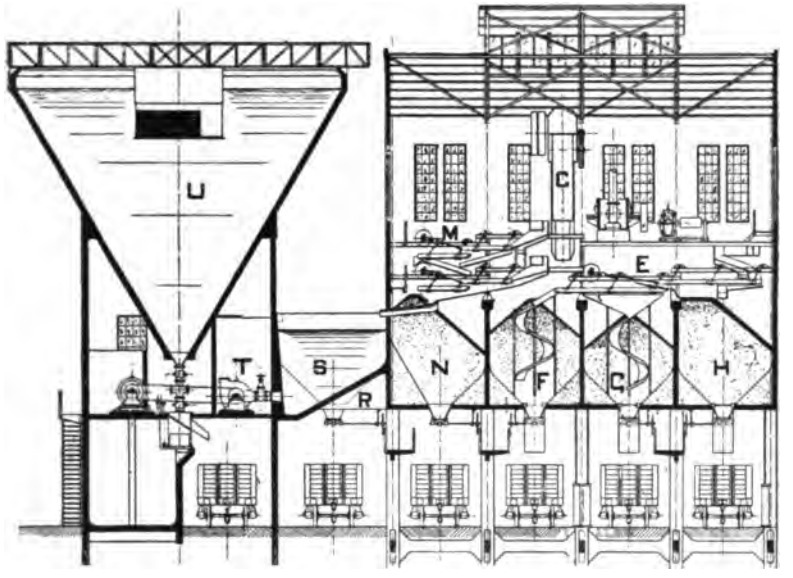


FIG. 3.—LONGITUDINAL SECTION OF CONTINUOUS WASHERY.

With this system, a current of water on the vibrating screens is practically non-existent, as the bulk of the water is drained off on the two sieves *B* and *G*, and consequently the slurry is retained.

The greatest portion of the water is, of course, drained off sieve *B*, where the fine coal arrives along with the water in which it has been washed. The coal banks up on this drain-sieve to a depth of 4 to 6 inches; a certain proportion of the slurry is retained in this layer of coal, and the mixture moves gradually down the incline on to the vibrating screens. The water with

such slurry as passes through sieve *B* is delivered into settling-tanks, from which the settlings are brought back on to the slurry sieves.

The constructors of this appliance, which is called the "British slurry-refiner," use a large conical settling-tank (as shown in Fig. 3), in connexion with their plants, into which the water collecting in the shoot *C* (Fig. 2) is pumped, the slurry settling down and flowing by gravity on to sieve *G*. The slurry has to be in a certain liquid state before it will flow through the pipes. This condition, however, owing to the large conical tanks, can be regulated to a nicety, for which reason the water proportion in the slurry is kept at a minimum. On arrival at sieve *G*, the excess water is immediately extracted, this water flowing back again to the pump and passing again through the settling-tank; whereas the water which subsequently drains off the shakers *J*1 and *J*2 is filtered on sieve *D*1, before it returns.

With the combination of this slurry-refiner and the elevated settling-tank mentioned, it has been found possible to work a washery, year in and year out, without any outlet whatever.

With regard to the arrangement of a washery at a minimum cost for labour, handling, and washing, Figs. 3 and 4 illustrate a plant in which this desideratum has been carefully studied. In the first place, the feed-hopper is attached direct to the screening plant, the coal being delivered direct from the screens by means of a conveyor into a feed-hopper, thus doing away with the loading at the screening plant and again unloading at the washery.

If it should be found desirable to wash coal coming in by railway, a small feed-hopper is arranged alongside the washery feed-hopper, and is provided with automatic tipplers, the coal being elevated out of this small hopper into the main feed-hopper. The coal is elevated into the washery by the feed-elevator *C*, where it is subjected to a double washing in the washer-box *D* (Fig. 4), in the first part of which (*D*1) the heavy dirt and in the second part (*D*2) the lighter dirt is extracted. The washed coal flows along to the vibrating screens *E* (Fig. 3), where it is separated into fine coal, singles, doubles, and trebles. The three last-mentioned are delivered into separate bunkers, *H*, *G*, and *F*, from which they are loaded into railway-wagons on separate railway-sidings. The fine coal collects with the washing-water in the smudge-sump *J* (Fig. 4), and after being elevated by the smudge-elevator

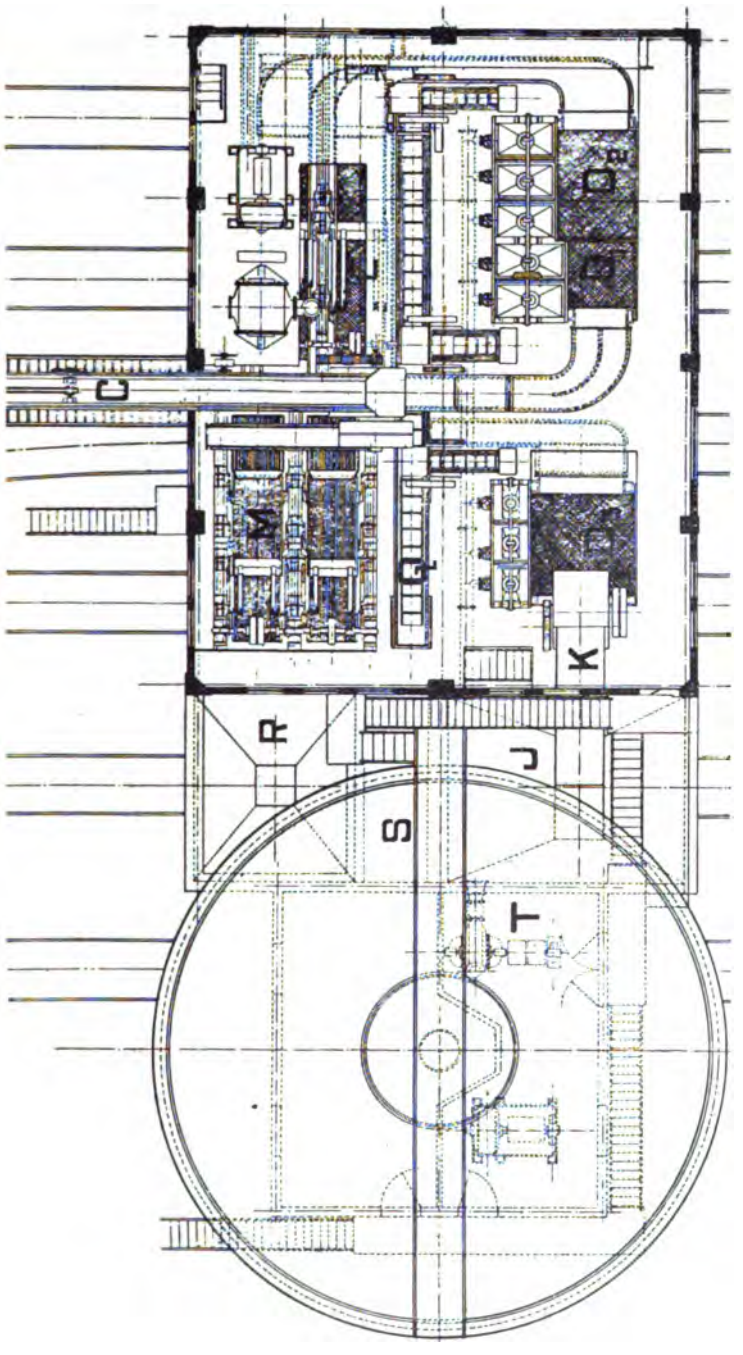


FIG. 4.—PLAN OF CONTINUOUS WASHERY.

*K* into the fine-coal washer-box, undergoes a third washing before it passes on to the fine-coal draining arrangement and slurry-refiner.

The water from the fine-coal sieves collects in the pump-sump *S* (Fig. 3), and is pumped by the centrifugal pump *T* into the settling-tank *U*, where the slurry settles down, and is pressed by the gravity of the water on to the slurry-refiner *M*. The fine coal and slurry are then delivered direct into the loading bunker *N*, from which the mixture is loaded into railway-wagons.

The dirt is elevated and drained in three separate dirt-

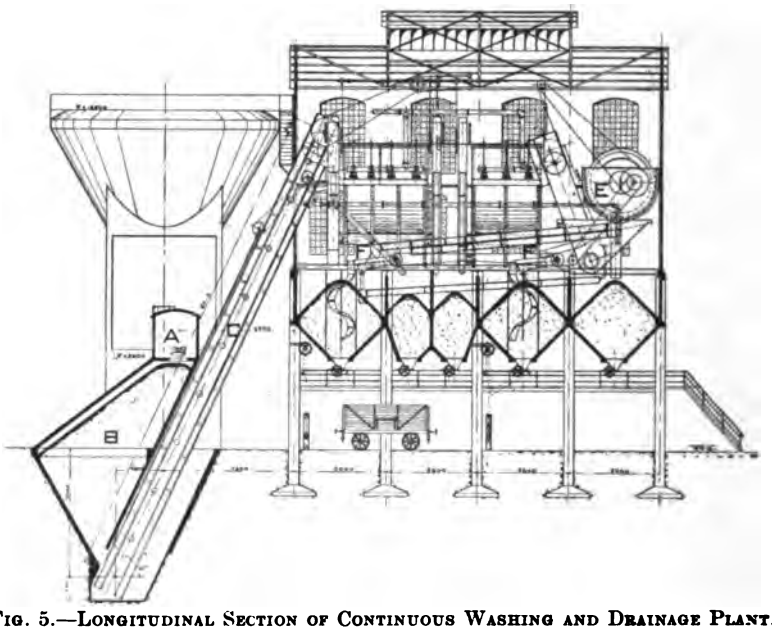


FIG. 5.—LONGITUDINAL SECTION OF CONTINUOUS WASHING AND DRAINAGE PLANT.

elevators attached to the washer-boxes before it is delivered on to the scraper-conveyor *Q* (Fig. 4), which carries the dirt to the dirt bunker *R*, and is then loaded into railway-wagons.

For the working of the whole of this washery of 125 tons per hour capacity, two men are sufficient, not counting, however, the men required for loading the washed products into railway-wagons and for regulating the traffic under the washery. As no handling of the coal between the screening plant and washery is required, the cost of loading the wagons under the washery should be charged to the screening plant, because if

there were no washery, the wagons would have to be loaded at the screening plant. If the washery is separate from the screening plant, and the coal has to be loaded into railway-wagons, the unloading and reloading at the washery would then become an additional charge to the cost of the two men mentioned for running the washery.

This minimum of labour is made possible by the fact that the whole of the washing is continuous, and all working parts are well within sight of one single man from any point of the plant. There are also no secondary settling-tanks or water-pits in connexion with this plant, all points subject to wear and tear are get-at-able, and any repairs are thus easily carried out.

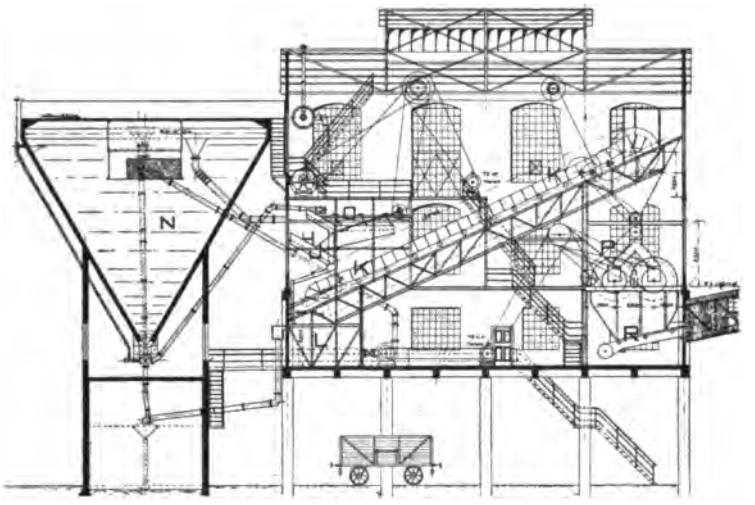


FIG. 6.—LONGITUDINAL SECTION OF CONTINUOUS WASHING AND DRAINAGE PLANT.

This type of plant is suitable for ordinary colliery purposes where perfect drainage of the fine coal is not essential, and where a moisture in the fine coal of 12 to 15 per cent. above the natural moisture in the coal is permissible. This moisture would be too high for washeries the slack from which is intended to go direct into coke-ovens. Additional drainage for such can either be arranged for by means of a conveyor, as illustrated in Fig. 6, which again makes the washery continuous, or by means of drainage-bunkers, as shown in Fig. 7, which latter system is not continuous.

The washery (Figs. 5 and 6) is supplied with coal by means of

the belt-conveyor *A* into the feed-hopper *B*. The feed-elevator *C* delivers the coal into the washery, where it is subjected to the same treatment as that described for the previous plant, with the exception that the circular revolving screens *E* are, instead of vibrating screens, used for separating the coal into nuts, peas, and slack.

The nuts and peas are swilled down troughs on to the drain-tables *F*; the drained nuts go into bunker *G*1 and the peas into *G*2: both bunkers are provided with spiral shoots for the prevention of breakage. The drain-water is returned to the pump-sump *L* (Fig. 6).

The washed fine coal along with the washing-water arrives on the drain-sieves *J*, over which the drained fine coal passes into the draining conveyor *K*. The water and slurry from the drain-sieves *J* collect in the sump *L*, whence they are pumped into the settling-tank *N*, in which the slurry settles down and is brought back on to the slurry-refiner *O*, where it is drained before delivery into the draining conveyor *K* on top of the fine coal. The coal from the sieves *J* forms a layer in the bottom of the perforated compartment before the drained slurry is added on top. The mixture is thus graduated, and the remaining moisture quickly drains away all water collecting in the pump-sump *L*.

The draining conveyor, which requires about ¾ hour to complete the journey from one end to the other, delivers the contents to the disintegrator *P*, the crushed coal falling on to the belt-conveyor *R* and being conveyed into the coke-oven service bunker.

The fine coal and slurry sieves are in this instance proportionately shorter and of smaller area than those described for the previous washery, where a good margin is essential to prevent any water from getting into the fine-coal bunker. In the case of the draining conveyor this is not necessary (and would also for structural reasons be rather difficult), as any excess moisture in the mixture that reaches the draining conveyor would drain away quickly through the perforations of the compartments.

The washery illustrated in Figs. 7 and 8 is identical with the washery shown in Figs. 3 and 4, with the addition only of drainage-bunkers and crushers. The coal and slurry, after passing over the drain-sieves *G*, are delivered by means of the scraper-con-

veyor *H* into eight double sets of bunkers, each set holding 200 tons of fine coal, or a total draining capacity of 1,600 tons. Approximately 50 tons of fine coal per hour will be delivered into these bunkers, four hours being required to fill each set of bunkers.

As it has been assumed that the plant will work 16 hours per day, four sets of bunkers would be filled each day. The coal

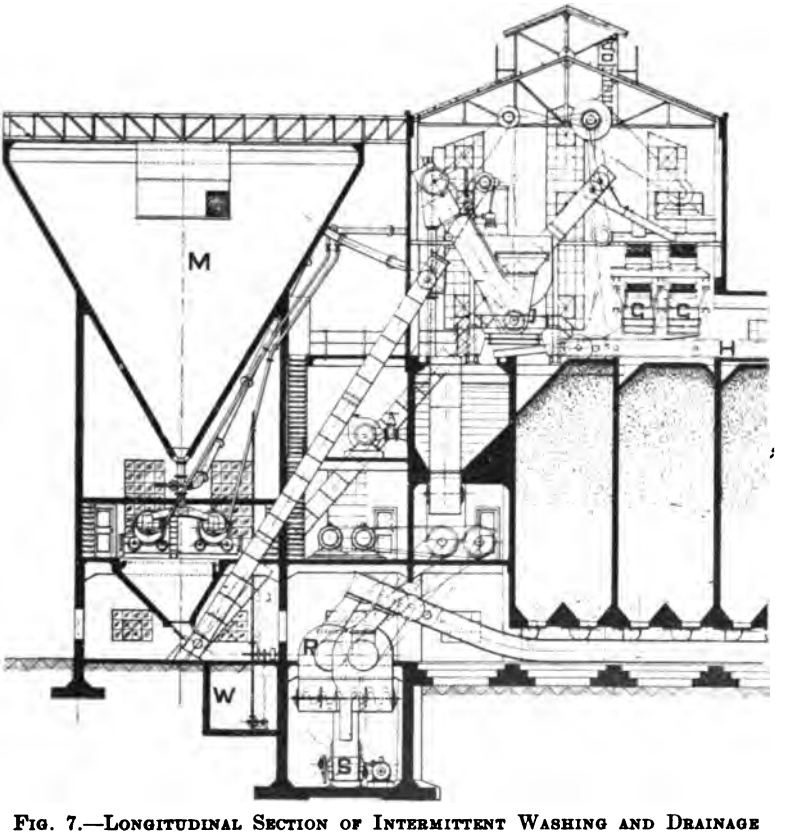


FIG. 7.—LONGITUDINAL SECTION OF INTERMITTENT WASHING AND DRAINAGE PLANT.

remains, on an average, 48 hours in the bunkers for final drainage, after which it is discharged through four openings at the bottom of each set of bunkers into the scraper-conveyors *Q*, which deliver the coal to the disintegrators *R*. The crushed coal is fed on to the belt-conveyor *S*, which delivers the coal into the coke-oven service bunker.

The fine coal with the slurry is deposited in the drainage-bunkers, with an excess moisture of about 15 per cent., and

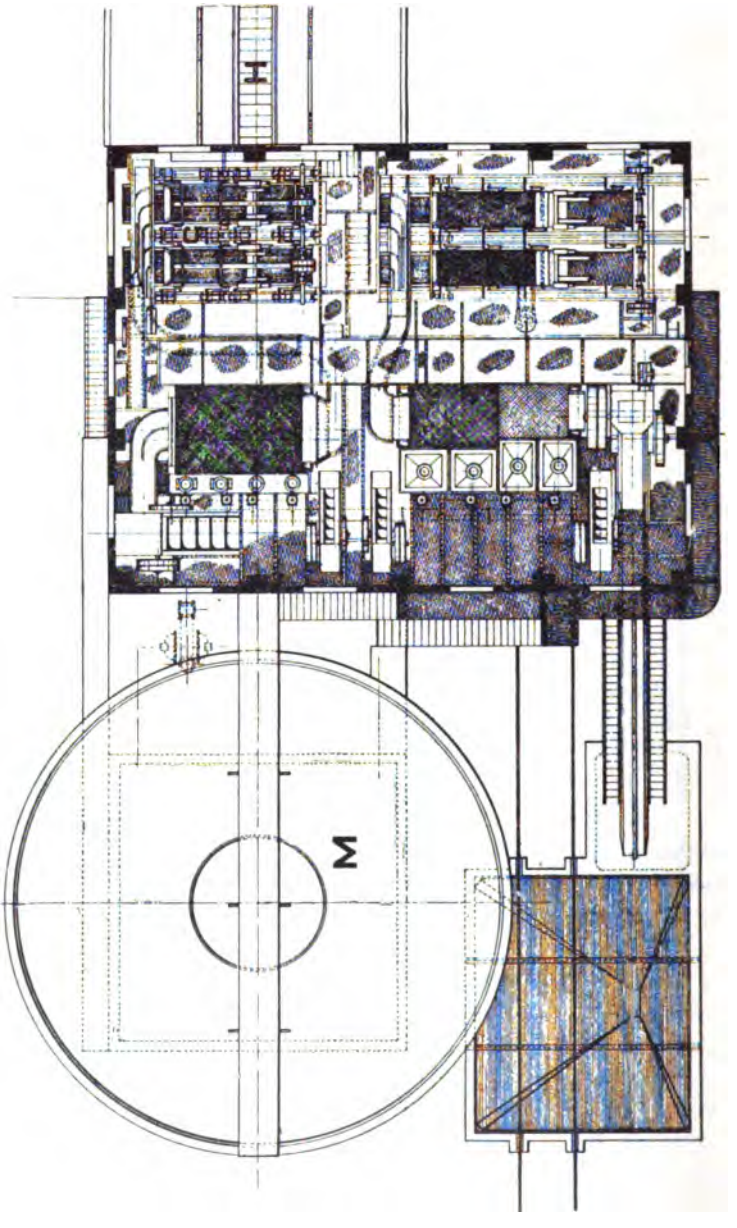

Fig. 8.—Plan of Intermittent Washing-and-Drainage Plant.

it is anticipated that 8 to 10 per cent. will percolate through the drain-pipes and slides at the bottom of the hoppers during

48 hours. The drain-water flows to the drain-sump $W$, and is then pumped into the settling-tank $M$.

A washery with drainage-bunkers, is split up into two distinct parts, which require separate supervision and workmen. At least one man will be required to regulate the coal from the drainage-bunkers into the scraper-conveyor, another to attend to the crushers and the belt-conveyor to the service bunker, and, in addition, three men will be required in the washery: whereas with the continuous washing-and-draining plant three men can easily attend to the whole of the work to be done, instead of five with what may be called the "intermittent" process.

With the continuous washery storage is not provided, and in case of a serious breakdown the coke-ovens might go short of coal, if the service bunkers at the time should be empty. These service bunkers are usually calculated to give a two-days' supply to the coke-ovens, or enough to keep the ovens going over the week-end. If a breakdown should occur, say, on a Monday morning, when the service bunker is practically empty, the coke-ovens would have to stop for the time being.

With drainage-bunkers of 1,600 tons capacity, 1,400 tons of coal should always be available for supplying the coke-ovens during regular work. The drainage capacity of a washery, however, cannot be reckoned as storage also, as the coal has to remain in the bunkers for 48 hours before it is sufficiently dry to go to the coke-ovens.

The coke-ovens, in this instance, require 3,200 tons of coal per week, or, say, 20 tons per hour per 24-hour day. $48 \times 20 =$ 960 tons of coal, or, say, five bunkers out of eight should be left until washing is recommenced, leaving a net storage of 400 tons. This figure may be increased by reducing the time allowed for drainage and by charging wet coal into the ovens, but the ovens would suffer too much if this practice were often resorted to.

With bunkers there is, however, the advantage that, in case of a breakdown, it is immediately known what stocks are in hand, and the working of the coke-ovens may be so regulated as to take the coal in the storage-bunkers short of a minimum that must remain to allow sufficient time for the new coal to drain properly.

On the face of it, the drainage-bunkers seem to have the

advantage, provided that there is not much difference in price ; but if a service bunker of an additional 400 tons capacity be installed, the advantages are all in favour of the continuous washery :—

(1) There is the saving of two men, which alone represents at least £150 in wages per year. At ten years' purchase this would probably more than equalize the increase in cost for the larger service bunker, not to mention the advantages of managing the plant with fewer men, especially under existing labour difficulties.

(2) The draining conveyor receives the wet coal at one end and delivers the dry coal automatically at the other end. There is no trouble arising from coal sticking in this conveyor—so very common in the case of drainage and storage-bunkers.

(3) The draining conveyor moves only very slowly—about 18 inches per minute—in comparison with the

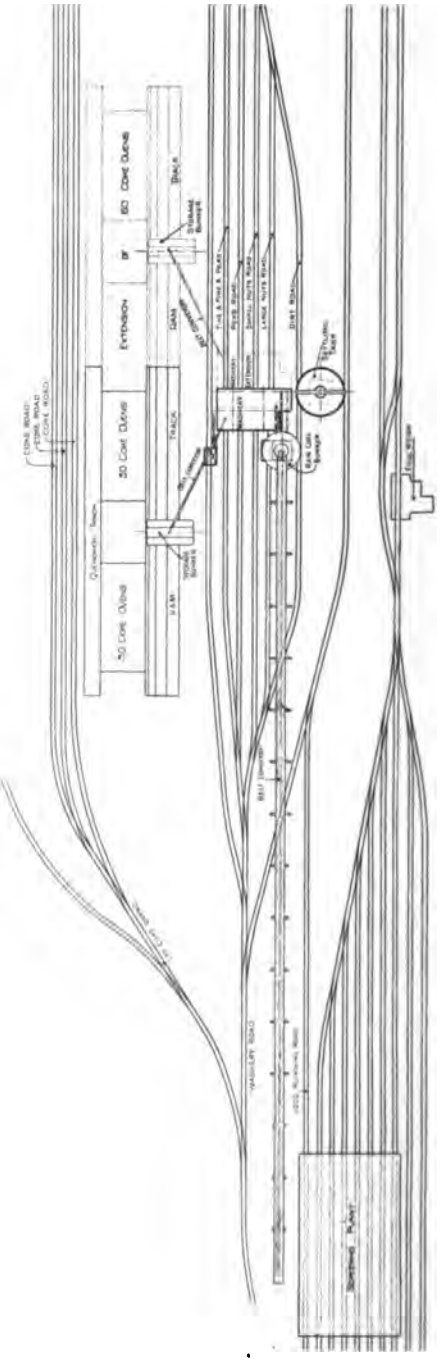

FIG. 9.—PLAN SHOWING ARRANGEMENT OF WASHERY AND COKE-OVENS.

distributing and collecting conveyors in connexion with the bunkers, which rarely travel at less than 75 feet per minute. The wear and tear, therefore, of the draining conveyor is negligible as compared with the fast-running conveyors.

There are two further points to consider in the lay-out of the washery, one of which is very often entirely overlooked, namely, siding accommodation, which may become quite important with washeries of large capacity, especially when the coal is brought in railway-wagons.

Another difficulty that must be overcome, especially where washeries are connected direct to the screening plant, is the irregularity with which the coal arrives; and although the washery may, on an average, have to deal with 1,000 tons of coal in eight hours, the coal during this time may arrive at the washery at the rate of 250 tons per hour, with which a 125-ton-per-hour washery could not deal at this rate.

Fig. 9 shows a plant laid out to meet these requirements. Sidings are provided for stocking empty wagons at the upper end of the washery for a whole day's washing, with sufficient room at the bottom end to allow the loaded wagons to collect there. Separate sidings are arranged for each size of washed coal, so that no shunting operations whatever are required to deal with the whole of the coal in the washery. The coal is delivered by means of a belt-conveyor of a capacity of 200 tons per hour direct into a feed-hopper of 900 tons capacity. A separate feed-hopper of 100 tons capacity is arranged at the top of this bunker, to which one of the feed-elevators for the washery is attached. If at any time more coal arrives than the washery can deal with, the surplus automatically falls into the large storage-hopper. A separate elevator is attached to this large hopper, which elevates the coal into the washery when required.

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The PRESIDENT (Mr. Leonard R. Fletcher) moved, and Mr. SYDNEY A. SMITH seconded, a vote of thanks to the author, and the resolution was adopted.

Mr. VINCENT BRAMALL (Manchester) said that Mr. Hunter had offered no explanation as to how the dirt in the sludge was to be got rid of in the washing process. He saw no means by which

the sediment in the settling-tanks could be separated and taken out. They had been told that the same water could be used over and over again, but that was not his experience. He had found at the Foggs Colliery that if the same water were used two or three times, the coal became the colour of clay, and on that account was difficult to sell. The fine fireclay coated the coal, which, after being washed, had to be syringed with fresh water before it was sent away.

Mr. J. DRUMMOND PATON (Manchester) asked whether the author had treated in the washeries coal-dust containing more than 5 per cent. of moisture, because it seemed to him that consideration had been given mainly to wet coal. He (Mr. Paton) had followed the subject closely for several years, and his experience was that in the majority of cases with which they had to deal in Lancashire the coal was dry.

The speaker had communicated a paper to the Society on the subject,* in which he had endeavoured to impress upon coal-owners the advantages of a dry-dust treatment. He had also emphasized the importance of washing coal in which there was a maximum amount of ash, and he would refer the members to page 434, in which an examination had been made of the physical properties and the ash of a Lancashire slack. In fact, in some cases it had been possible by such an examination to pass forward certain portions of the coal where the ash content was so low that it really did not require washing, and this coal could be virtually sold as " washed " slack.

His experience had proved that it was practically impossible to enrich the small coal under 1 millimetre cube, and if that material was allowed to pass into the washery, it produced a thick viscous washing fluid, with all its attendant troubles, whilst the slurry which eventually issued from the washery was not in any way enhanced in value by its passage through the washery, especially the " flour-dust " portion.

If this flour-dust coal were permitted to enter the washery (especially if it had a high ash content), it produced a treacly washing water in which there was no distinctive action. In many cases this water caused a coating of dirt on the washed

* "Small Coal and Dust: its Production, Prevention, Treatment, and Utilization, with Special Reference to Dry Mines," *Trans. Inst. M. E.*, 1913, vol. xlv., page 421.

nuts, which was objectionable from a commercial point of view. The dust-coal from 1 millimetre downwards contained the maximum ash content, and if it could not be enriched in the washery, the best policy was to extract it beforehand. He would specially ask Mr. Hunter to state whether he had recently done any development work on dry-screening, and, if so, the nature of the same.

The PRESIDENT said that Mr. Hunter had distinguished between "continuous" and "intermittent" washeries. By "continuous" he assumed that the author meant a washery in which coal was conveyed direct from the screening plant by a conveyor-belt, and by "intermittent" one where the coal was loaded into wagons from the screens and unloaded again from the wagons into the washery. The first method ought to be the cheaper of the two, but there were difficulties in connexion with a continuous washery, on which the author had briefly touched, and for which he had suggested a simple remedy. The supply of material for the washery did not always come evenly from the pit, and that was an important point to be reckoned with when the erection of a washery was under consideration. It was very annoying to have the pit stopped on account of the washery being overloaded after every effort had been made to provide a plant capable of dealing with all the small coal likely to come from the workings. For some reason or other the coal coming from the workings contained more slack at one period than it did at another, the result being that the washery was overloaded perhaps for one hour and had not enough to do the next hour. With a suitably arranged storage-bunker, as outlined by Mr. Hunter, this difficulty could be easily overcome. Mr. Hunter had recommended washing first and sizing afterwards, but there was much to be said in favour of sizing first and washing afterwards, and he believed that the washing would be more efficient if the sizing were done first. He would, therefore, like to hear Mr. Hunter's reasons for his recommendation.

Mr. FRANK N. SIDDALL (Bolton) asked whether the author intended to convey the impression that the water was used over and over again when he stated that "it had been found possible to work a washery year in and year out without any outlet whatever." If that were so, there might be a difficulty on account of

the water becoming very thick and dirty. He had had experience of a washery where the fine dust (from a millimetre downwards) made all the difference in the world to the efficiency of the treatment. After the washery had been working for some time, the water became like a thin cream or whitewash, and it dusted the washed nuts, or whatever they might be, to such an extent that customers would not have them at any price. The fact that the coal had been washed reduced its value by several shillings a ton, because it was plastered all over with fine dust. An effort was made to extract the dust by putting in other screens, and this made a great difference in the efficacy of the washery, not only as to the amount of material put through, but also as to the amount of water used and the cleanliness of the coal treated. Very fine dust was absolutely valueless commercially—it was not worth washing—and if a system could be devised by which the dust could be eliminated before the coal was washed, there would be less water used and a finer product would be obtained.

Mr. J. DRUMMOND PATON stated that his previous remarks had reference to Lancashire coal. In the majority of cases in that area the flour-dust coal contained a high ash content, but in other coals that he had investigated, especially those from Wales, the flour-dust coal was almost pure. It did not, however, matter whether the small flour coal was dirty or pure, as no method of washing had yet been established which improved dust under 1 millimetre cube. Consequently, if its presence in the washery was detrimental, it should be removed beforehand.

Mr. ARTHUR STOKER (H.M. Inspector of Mines, Prestwich) asked whether the previous speakers desired to eliminate coal-dust, stone-dust, or clay-dust. The clay or stone-dust, which was often present in very fine particles, caused the water to become dirty or viscous; but if this dust were eliminated before washing, it would be interesting to know what they suggested should be done with it.

Mr. J. DRUMMOND PATON said that, presuming the dust was very fine and of high value, and it was taken out by a dry-extraction system, the possibility of its causing trouble in the washing water would be removed in the most effectual way. If removed dry, it could be passed back for dilution with the small washed

coal for coking purposes. It had also a much higher thermal value for firing in the boilers when in the dry state. With regard to its final utilization, he was convinced that before long this class of material would be treated in low-temperature distillation systems for the recovery of oil. The resultant coke would be eventually gasified for gas-power systems, and the sulphate of ammonia recovered.

Mr. Tom Stone (Wigan) agreed that at the present time extracted dry dust was a very nasty commodity with which to deal, as it consisted of anything from practically pure coal-dust to dust with a high percentage of incombustible matter. There were collieries where the dust was collected in drums or in a vacuum apparatus, but even then there was a difficult problem to solve in finding a suitable method of dealing with it after its collection on the surface. One suggestion was that it should be made into briquettes, and this was possible where the dust was of good quality; but such a solution would not apply equally to all collieries, because of the varying qualities of the dust recovered.

Mr. Sherwood Hunter (Manchester), in reply, said that the intention of his paper was to discuss "economies in coal-washing." He should have qualified this by adding "modern washeries," as most of the questions raised were based on experiences with washeries which he felt convinced the speakers themselves would not call "modern" plants, and must have been working for over 15 years, or probably longer.

The "slurry" problem in a modern plant had been solved, as slurry could be washed, and this was done in most washeries that had been put down during the last ten years. If the slurry was kept separate either in the wet or in the dry state, it was practically a useless product. In a modern washery, therefore, where economies had to be studied, it was essential that the slurry should be recovered in such a condition that it could be mixed with the fine coal without detriment to the value of that coal.

The washeries described in his paper were all laid out for that purpose. The whole of the coal was subjected to a double washing before classification, after which the fine coal was re-washed separately. The slurry, which was extracted from the fine coal after it had been thus washed three times, went with the

washing-water into the settling-tank, where it was concentrated, and then returned to the washery to be mixed with the fine coal.

In order to prove that the slurry was washed, or enriched, during its passage through the washer-boxes, an independent test was taken more than two years ago, and it was found that the dirt from the dirt-elevators contained the following:—

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| First elevator... | 1·9 | per cent. | of dirt | below | 1/50-inch mesh, | with 60 | per cent. | of ash. |
| Second ,, ... | 5·6 | ,, | ,, | ,, | ,, | 68·2 | ,, | ,, |
| Third ,, ... | 19·6 | ,, | ,, | ,, | ,, | 69 | ,, | ,, |

The size of the dirt-particles was half that mentioned by Mr. Drummond Paton, namely ½ millimetre cube. If there was dirt of this size, the raw coal-dust must, of course, have been deprived of dirt substance, and therefore enriched to the extent of the dirt extracted.

It was due to the system of drainage illustrated in Fig. 2 that the water in the settling-tank did not reach such a consistency that it had to be changed. In the case of ordinary drainage elevators with perforated buckets, which were generally used for the recovery of fine coal and slurry, this was quite likely, and the faults of this system were explained in the paper.

With regard to the classification of the coal before washing, as against the system described in the paper, namely, to wash first and then classify, theoretically speaking there should be no difference in either method, because the coal was separated in both systems in accordance with the specific gravity of the material. The mistake was generally made of comparing laboratory results obtained in *still* water with those obtained in washer-boxes in *flowing* water. The effect was quite different, and must be so, as was proved by the foregoing figures relating to fine dirt. If the theory of still water were applicable to flowing water, there would be no small dirt below $\frac{1}{50}$ inch, but all the large coal, coming out with the dirt in the first washer, over which all the coal below 3-inch mesh had gone.

From a practical point of view the advantages seemed to be all in favour of washing first and then classifying, because there were only two outlets for dirt and one for coal in the double washer-box and in the re-washer one outlet of dirt and one outlet of coal for washing the whole of the coal at the rate of 125 tons per hour. With separate washing boxes for previously sized

products, however, there would be at least fifteen washer-boxes with fifteen outlets of coal and fifteen outlets of dirt, and these could not be attended to properly by two men required for the washery described in the paper. With equal attention, therefore, this system should give better and in any case more reliable results.

In the case of any variation in the size of the coal with which a "classifying-before-washing" plant was laid out to deal, the feed into the washery would always have to be so regulated as to prevent the coal that was going into any individual washer-box from exceeding the maximum quantity which that box was capable of washing.

Assuming dust-extraction to be practicable with a 125-ton washery, as described, the site of the screening plant for the extraction of the dust would about equal in area the site for the whole washery. Separate attendance would be required, and the cost of wear and tear of the screens alone would probably exceed that of the upkeep of the whole washery laid out to deal with the slurry. This would be especially the case if there were any trouble with damp coal, a trouble which could hardly be prevented, especially if the coal were brought to the washery in railway-wagons. In addition, as water was met with in practically every pit, even a slight trickle into the wagons would cause the dust to cake, and this caked dust would choke the fine meshes of the dust-screens. Further, the dust-screens did not by any means extract the whole of the dust in the coal, but only about 80 per cent. at the best, so that 20 per cent. would still appear in the washery in the form of slurry. There was no doubt, however, that slurry troubles in badly-planned washeries were alleviated by dust extraction, but this would add to the cost of washing, even if the dust could be sold at a reasonable figure.

In conclusion, he might mention that in the washeries described the nuts and peas were not sprayed with fresh water, although the washing-water was never changed. The slurry was extracted and mixed with the fine coal; the washing-water remained thin, and never reached such a consistency as to discolour any of the washed products, including the dirt.

# THE MINING INSTITUTE OF SCOTLAND.

## ANNUAL GENERAL MEETING,

HELD IN THE ROOMS OF THE INSTITUTE, 39, ELMBANK CRESCENT, GLASGOW, APRIL 8TH, 1916.

MR. DAVID M. MOWAT, PRESIDENT, IN THE CHAIR.

The minutes of the last General Meeting were read and confirmed.

The SECRETARY read the annual report of the Council, and a duly audited abstract of the Treasurer's accounts for the year, which were unanimously approved, as follows:—

## ANNUAL REPORT OF THE COUNCIL, 1915-1916.

The Council beg to submit their thirty-eighth annual report to this the thirty-ninth annual meeting of the Institute. The number of members on the roll at this date is as follows:—

| | |
|---|---|
| Honorary members ... ... ... ... ... | 4 |
| Life members ... ... ... ... ... ... | 8 |
| Life associate member ... ... ... ... | 1 |
| Members (subscription, £2 2s.) ... ... ... | 201 |
| Members (subscription, £1 5s.) ... ... ... | 345 |
| Associate members ... ... ... ... ... | 38 |
| Associates ... ... ... ... ... ... | 18 |
| Students ... ... ... ... ... ... | 9 |
| Non-federated members (subscription, £1 1s.) ... | 10 |
| Non-federated member (subscription, 10s. 6d.) ... | 1 |
| Total ... ... ... ... ... ... | 635 |

This compares with the number on the roll last year as follows:—

| | | |
|---|---|---|
| On the roll at April, 1915 ... ... ... ... | | 657 |
| Added during the year ... ... ... ... | | 38 |
| Total ... ... ... ... ... ... | | 695 |
| Died ... ... ... ... ... ... | 8 | |
| Retired ... ... ... ... ... | 13 | |
| Struck off through non-payment of subscription ... ... ... ... ... | 39 | |
| | — | 60 |
| At present on the roll ... ... ... ... | | 635 |

This shows a net decrease in membership of 20. The continuance of the war has unfavourably affected the Institute as regards the addition of new members.

The following papers, with discussions thereon, have been placed before the members, and published in the *Transactions*:—

"Presidential Address." By Mr. D. M. Mowat.
"Forming a Shaft-pillar in Thin Seams." By Mr. James Black.
"Rescue-station Organization: the Resident-brigade System *versus* the System of non-Resident Brigades." By Mr. Henry Briggs.
"A Method for the Rapid Estimation of Oxygen and Blackdamp in the Air of Safety-lamp Mines." By Mr. Henry Briggs.
"Lining Shafts with Concrete Z-blocks." By Mr. Marcel Gillieaux.
"An Auxiliary Aid Outfit for Attachment to Self-contained Rescue-apparatus." By Mr. Michael McCormick.

These papers have all been of a high standard, and have led to valuable, instructive, and interesting discussions. The Council would be pleased if as many members as possible would take part in the discussions. In addition to the papers noted above, excerpt copies of a paper on "Compressed Air for Coal-Cutters," by Mr. Sam Mavor, which was read at the Annual General Meeting of The Institution of Mining Engineers, held at Leeds, have been distributed to the members and discussed. The Council would be glad to receive the assistance of members in securing papers for the general meetings of the Institute.

As in former years, the general meetings have been held alternately in Glasgow and Edinburgh on Saturday afternoons, and the attendances at the meetings have been very satisfactory.

Owing to the continuance of the war, no excursion or dinner has been held during the past session. A Roll of Honour, containing the names of 52 members at present serving in His Majesty's forces, has been compiled. Of these four have fallen in battle, namely, Lieut. Andrew Burt, Lieut. William J. N. Dunnachie, Lieut. Campbell King, and Lieut. James Wilson; and three have gained military distinction for bravery in the field, namely, Major Ritson (the Distinguished Service Order), and Lieuts. H. W. Boyes and David McKelvie (the Military Cross).

A committee has been appointed to consider and report on "A Standard Method of Ascertaining the Efficiency of Mine Fans."

Seven meetings of the Council have been held during the year.

## THE TREASURER IN ACCOUNT WITH THE MINING INSTITUTE OF SCOTLAND, FOR THE SESSION 1915-1916.

| RECEIPTS. | £ s. d. | £ s. d. |
|---|---|---|
| To Balance from Session 1914-1915 ... ... | | 468 13 0 |
| „ Members' Subscriptions— | | |
| „ Arrears— | | |
| 10 Members, Session 1914-1915, @ 42s. | 21 0 0 | |
| 15 „ „ „ 25s. | 18 15 0 | |
| 1 Associate member, „ „ 42s. | 2 2 0 | |
| 1 Associate, „ „ 25s. | 1 5 0 | |
| 1 Student, „ „ 25s. | 1 5 0 | |
| | | 44 7 0 |
| „ Current— | | |
| 180 Members, Session 1915-1916, @ 42s. | 378 0 0 | |
| 310 „ „ „ 25s. | 387 10 0 | |
| 10 „ „ „ 21s. | 10 10 0 | |
| 1 Member, „ @ 10s. 6d. | 0 10 6 | |
| 37 Associate members, „ @ 42s. | 77 14 0 | |
| 11 Associates, „ „ 25s. | 13 15 0 | |
| 5 Students, „ „ 25s. | 6 5 0 | |
| | | 874 4 6 |
| Paid in advance— | | |
| 5 Members, Session 1916-1917, @ 42s. | 10 10 0 | |
| 7 „ „ „ 25s. | 8 15 0 | |
| | | 19 5 0 |
| „ Interest ... ... ... ... ... | | 37 16 4 |
| „ Sundries ... ... ... ... ... | | 1 3 9 |
| | | £1,445 9 7 |

| PAYMENTS. | £ s. d. | £ s. d. |
|---|---|---|
| By Printing and stationery ... ... ... | | 73 3 5 |
| „ Books and bookbinding ... ... ... | | 2 10 5 |
| „ Rents ... ... ... ... ... ... | | 35 16 0 |
| „ Salaries ... ... ... ... ... | | 108 8 |
| „ Stamps, telegrams, carriages, etc. ... | | 14 12 10 |
| „ Sundries ... ... ... ... ... | | 14 1 6 |
| „ The Institution of Mining Engineers for Calls, etc. ... ... ... ... ... | | 622 0 7 |
| „ Expenses of representatives on the Council of the Institution ... ... | | 51 10 5 |
| „ Cash in Post-office Savings Bank ... | 17 15 10 | |
| „ „ Invested in 2½-per-cent. Consols ... | 80 15 0 | |
| „ „ „ Motherwell Burgh Loan | 250 0 0 | |
| „ „ in Clydesdale Bank on deposit receipt ... ... ... ... | 100 0 0 | |
| „ „ in Clydesdale Bank on current account ... ... ... ... | 74 7 7 | |
| „ „ in Treasurer's hands ... ... | 0 8 0 | |
| Balance ... .. ... ... | | 523 6 5 |
| | | £1,445 9 7 |

## CAPITAL ACCOUNT.

| | £ s. d. | | £ s. d. |
|---|---|---|---|
| To Balance from Session 1914-1915 ... ... ... | 582 2 0 | By Balance, invested in £800 North British Railway 3-per-cent. debenture stock ... ... ... | 582 2 0 |
| | £582 2 0 | | £582 2 0 |

Glasgow, *April 4th*, 1916.—Examined, compared with vouchers, and found correct.

THOMAS BROWN
JOHN BARROWMAN } AUDITORS.

A vote of thanks was awarded to Messrs. Thomas Brown and John Barrowman for their services as Auditors.

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The following gentlemen, who had been duly nominated, were elected:—

MEMBERS—

Mr. DAVID DUNCAN, Civil and Mining Engineer, 12, Buchanan Gardens, Mount Vernon, Glasgow.

Mr. HUGH WADDELL, Colliery Manager, Riggonhead Colliery, Tranent, East Lothian.

Mr. JOHN B. WARDLAW, Colliery Manager, Jealgora, Jamadoba P.O., District Manbhum, India.

ASSOCIATE MEMBER—

Mr. ARTHUR F. PRICE, Wire Rope Agent, 50, Cranworth Street, Hillhead, Glasgow.

ASSOCIATE—

Mr. JOHN PATRICK GRAHAM, Mining Engineer, Safaga, Upper Egypt.

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## ELECTION OF OFFICERS, 1916-1917.

Mr. J. BALFOUR SNEDDON (Mid-Calder), in moving the re-election of Mr. D. M. Mowat as President for the ensuing year, said that they were all glad that Mr. Mowat was to continue the direction of the Institute's affairs for another year.

The PRESIDENT (Mr. D. M. MOWAT) thanked the members for their vote of confidence in re-electing him. He could assure them that he would do his best to further the interests of the Institute.

The following gentlemen were elected as office-bearers in place of those retiring, for the session 1916-1917:—

PRESIDENT:

Mr. DAVID M. MOWAT.

VICE-PRESIDENTS:

Mr. ROBERT W. DRON. | Mr. JOHN MASTERTON.

COUNCILLORS:

| | | |
|---|---|---|
| Mr. JAMES BLACK. | Mr. RICHARD KIRKBY. | Mr. JAMES MORTON. |
| Mr. WILLIAM JARVIE. | Mr. MUNGO MACKAY. | Mr. ARCHIBALD SMELLIE. |

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## DISCUSSION OF MR. JAMES BLACK'S PAPER ON "FORMING A SHAFT-PILLAR IN THIN SEAMS."*

Mr. WILLIAM SMITH (Dalmellington) asked whether the shafts shown in Fig. 1 were the upcast and downcast shafts respectively, because if they were it seemed to him that there would be a serious leakage of air. There were only some 50 feet of coal between the levels, and if the coal was removed—no matter how well packed or stowed the space was—there would be considerable leakage, which would increase as the workings extended. Doubtless much would depend on the nature of the material used for stowage. Roof-weight would help to make it firmer and more airtight, but weight and crush was the very thing that Mr. Black sought to avoid. That argument would apply against the removal of a shaft-pillar in any case, more especially if the shafts were only the statutory distance apart.

Mr. ROBERT MCLAREN (H.M. Inspector of Mines, Airdrie) said that he did not think that the author would claim that the method he had described was original or new. The plan attached to the paper showed that the system was similar to that which was in operation many years ago, and was still practised at some collieries, namely, the room-and-rance system. The only difference in the present case was the driving in connexion with the shaft-pillar instead of the ordinary working. Mr. Black had pointed out very clearly the advantages of his method of driving, the principal advantage being the ease with which ventilation could be conducted to the faces. Those members who had had experience of driving shaft-pillars knew that it was a difficult matter to conduct the air from a certain distance in into the face, whereas with the method described that difficulty was, if not obviated, certainly modified.

He (Mr. McLaren) had been struck with one point in the paper. In a seam like that at Mr. Black's colliery why had not the whole seam been taken out altogether? This operation was not new, as he (Mr. McLaren) had seen it carried out successfully. In a thin seam where the waste was well-packed the strata certainly came down, but in his opinion they did not come down sufficiently to make any difference to the surface or the surface

* *Trans. Inst. M.E.*, 1915, vol. l., page 449; and 1916, vol. li., page 166.

buildings. It was quite evident, as pointed out by Mr. Smith, that Mr. Black aimed at preventing weight on the face. At the junction where the roads converged to the right and left there was a considerable area, and he was clearly of the opinion that the weight would go right into that area and greatly disturb the strata. It was quite obvious that Mr. Black would require to devise some other method of preventing the weight at this particular point.

Mr. Black claimed that it was better to leave in 30 feet of coal near the shaft before commencing with the longwall method of working. It would therefore appear from this that the author had not much faith in his own method, else he would hardly leave in a pillar of coal at this place, which he (Mr. McLaren) supposed was to prevent weighting round the shaft. The system described had much in its favour, but why have a width of 70 feet? In his opinion that was far too much, as quite good ventilation could be obtained by driving a roadway, say, 30 feet wide. In that way Mr. Black would prevent what he evidently desired to prevent, namely, weighting on the roof. It would be well, before adopting this system, to ascertain whether it could not be tried on a narrow road, anything, say, from 15 to 20 feet, with a "cundy" or opening on the opposite side for the ventilation to pass round.

Mr. John Gibson (Kilmarnock) drew the attention of the members to a paper by Messrs. W. H. and Basil H. Pickering on the same subject.* So far as the present paper was concerned, he did not agree with Mr. Black either in his practice or in his methods. As a matter of practice, the first point to consider in forming a shaft-pillar was the thickness of the surface, and this, he thought, Mr. Black had omitted. They could agree on the expediency of such an experiment where the surface might be only 20 feet thick and fairly firm; but if the surface was 20 fathoms thick, Mr. Black would be apprehensive every time that he contemplated the possibilities of danger to his surface machinery. The strata of which Mr. Black had given a section, however, were just the particular kind to be least affected in the way that he (Mr. Gibson) had indicated. They consisted of a firm post or sandstone, overlying about 5 feet of blaes. In ordinary circumstances there might be no difficulty in driving through that at

* *Trans. Inst. M.E.*, 1912, vol. xliii., page 428.

least 70 feet wide; but, supposing that the rock came down on the coal-head, that it was hard rock, and that the brushers blew it down. There was first of all the great difficulty and expense involved in carrying the dirt and *débris* about 12 yards along the wall. Then, again, very hard stones did not make good airtight packing, and consequently some soft material was required to make the buildings airtight. Unless the buildings were airtight, the value of the system which the author advocated was entirely lost. Mr. Black advocated it for a certain reason, and the premises of his argument were stated at the foot of page 449 as follows:—"Generally speaking, it is practically impossible to ventilate these narow places in a proper manner." If that contention were admitted, then it followed that there was a loss of time while the blasting operations were being carried on. That loss of time had to be paid for by the owners; and, further, it was obvious while the ventilation process was going through that the workmen would require to be paid considerably more than the current rate of wages in order to induce them to work under such conditions. On the general question, he did not think that he would be disposed to agree with Mr. Black that it was practically impossible to ventilate narrow places in a proper manner. He thought that, if narrow places were driven, even if gas were given off, with a forcing fan producing 4,000 or 5,000 cubic feet of air, discharging the air through air-pipes about 18 inches in diameter and fairly tight, and striking the face at a velocity of 300 feet, there would not be much gas left to complain of. The common practice was to drive these fans with a small turbine, or electrically, and in his opinion, if the current was available, the question was quite a simple one. He thought, however, that the most serious objection to the system described by Mr. Black was that it did not pay. In the colliery in question the amount of capital sunk would probably be £50,000 (it was immaterial for this argument whether the capital was £25,000 or £100,000). The Government were at present inviting every one to invest in 5-per-cent. Exchequer Bonds on the security of the British Empire, and therefore he did not think that a colliery shareholder would be immodest if he asked for a return of 10 per cent. on the money that he had invested in coal properties, especially in these troublous times. Faced with such a situation as this, he (Mr. Gibson) would sacrifice everything to speed in the matter of

output, because, after all, speed in that connexion was the main consideration. Mr. Black implied that he had driven these places at the rate of about 2 feet in the 24 hours. That meant that he proceeded at the rate of 4 yards per week, and at that rate of progression 37 weeks would be required to drive 150 yards. On the other hand, if he (the speaker) were to drive a place 12 feet wide, he would aim at 20 yards per week, even although coal-cutting machinery might not be available. Supposing, however, that he could only accomplish 15 yards per week, the work would still be completed in 10 weeks, and the dividend-earning stage would be brought nearer by 27 weeks than would be the case under Mr. Black's system. In addition, Mr. Black was risking something. The shaft-pillar and the extra cost that it entailed was his insurance premium. If he preferred not to pay it, he took the risk, but he could hardly claim credit for taking the risk. Given suitable circumstances (blaes underlying rock, and the coal not too hard), the method described by Mr. Black could be carried out; but, as a matter of general practice, he (Mr. Gibson) did not think that it had much in its favour.

Mr. William McCreath (Glasgow) asked what was the distance left by Mr. Black between the pits and the longwall workings to the rise of the pits beyond the shaft-pillars, and how he had arrived at it.

Mr. J. Balfour Sneddon (Mid-Calder) asked whether Mr. Black had been influenced in any way by observing the results of the method of working practised in his own district. He could quite see that if Mr. Black had a reserved area where he was allowed to take out only a certain percentage of coal, he might adopt this system with the view of watching carefully the result. Some members might be willing to try the method if they had some data to go upon.

Mr. James Kirkpatrick (Bothwell) said he had had some experience of this method of driving, although not in forming shaft-pillars. As an instance, he might mention a section of a mine in which the seams were in close proximity and the upper seams were standing in stoops, where in the opening of the lower seams it was necessary to drive a pair of narrow longwall roads—similar to those described by Mr. Black beyond the stooping area

above. Although at first there was some difficulty in connexion with the ventilation—due to the leakage through the stowage between the roads—this was overcome by the introduction of a Sirocco fan, and the system proved quite satisfactory. With regard to costs, he found the system adopted much cheaper than the ordinary stoop-and-room method of driving. There was much to commend this particular system in similar cases.

The PRESIDENT (Mr. D. M. Mowat) said that most of what he had intended to say had already been dealt with by the previous speakers. With regard to ventilation, he thought that it was very doubtful whether a satisfactory quantity of air could be carried into places driven by the method shown in Fig. 1. Unless the brushing or holing yielded sufficient soft material to make the buildings airtight, he did not think that the ventilation would be good. For instance, in the case of a rock-brushing the buildings would not be airtight. In a working of this kind, with walls 60 or 70 feet wide, no general subsidence took place, and there was, consequently, no weight on the buildings to consolidate them. It was only possible to make them moderately airtight by stuffing them with manure or other soft material. In a heading rising 1 in 4 for a distance of 150 yards, ventilation by means of air-tubes would be more efficient.

With regard to the speed of development, he was disposed to agree with the remarks made by Mr. Gibson. In an undertaking of this kind one of the first essentials was to get to the profit-earning stage, and in order to attain that rapidly the drawing of a little dirt was not a serious matter.

On the question of permanent advantage, he did not like the driving of roadways in such a room-and-rance system alongside the ribside. If the roof were sandstone, it would not break at all within the area taken out; but with almost any other kind of roof the roof broke along the ribside, and did not make a satisfactory roadway. In cases where this system was adopted, there should be a building between the ribside and the permanent roadway whenever possible. He did not think that Mr. Gibson quite appreciated Mr. Black's attitude in advocating this system. Mr. Gibson had referred to the difficulties which would be encountered if there was a deep cover of soft alluvial surface. Mr. Black's intention was that there should be no general subsidence by this

or any other method of forming shaft-pillars, so that the only effect of such a soft surface would be the provision of an increased area of pillar to afford adequate protection to the shaft and surface erections. He (Mr. Mowat) had had experience several years ago of driving a dook in an ironstone seam at a depth of about 250 fathoms. The roof and sides were very friable, and when the dook was driven as a fast place 12 feet wide, the sides came off in great slabs. It was practically impossible to keep the sides safe. The dook was widened out to 32 feet and roadside buildings composed of wooden pillars were put in, and the sides then became quite tough.

They as an Institute were much indebted to Mr. Black for bringing before them his practical paper. If they did not agree with him that it was the best method of forming shaft-pillars, it had its uses. In working thin seams under valuable property, the proportion of coal that could be safely extracted having been determined, that proportion could probably be taken out most profitably on such a system as that which Mr. Black advocated.

Mr. James Black (Shettleston) wrote that he knew when writing his paper that he was treading on dangerous ground, as did everyone who attempted to break down the strong barriers of conservatism that supported some of our mining methods. He was very much indebted to those members who had taken part in the discussion, and, even although some of their views did not coincide with his, the great respect that he had for their opinions was not diminished in the slightest degree.

He was very pleased to know that Mr. R. W. Dron had recently formed shaft-pillars on the system described by the writer, with results that fully justified the innovation. He (Mr. Black) considered that practical evidence such as that submitted by Mr. Dron was of infinitely greater value than all the theories that could possibly be put forward in connexion with a subject such as that under discussion. He believed that the method adopted by Mr. Dron in determining the size of the shaft-pillar to which he (Mr. Dron) had referred was the one most commonly adopted in Scotland in the case of ordinary strata lying at a moderate inclination. It seemed to serve the purpose well, and had the advantage of being easily applied. In the case of steep measures, however, the pillar had to be balanced, in order to compensate for the increased draw towards

the dip and the diminished draw towards the rise. In the shaft-pillar shown in Fig. 2 of his (Mr. Black's) paper, the draw extended over the rise side of the pillar towards the dip for a distance of fully 300 feet, although the depth of the seam from the surface at this point was only 126 fathoms. Mr. Dron considered that it would be advisable in the interests of safety to keep the longwall places about 100 feet away from the shafts. He (Mr. Black) thought that this was a matter that depended almost entirely upon the nature of the nether roof, and he agreed with Mr. Dron that in some cases it would be judicious to do as he (Mr. Dron) had suggested.

Mr. William Riddell seemed to be very apprehensive as to the security afforded by the system, but unfortunately omitted to advance any argument in support of his contention. The only apprehended danger was the risk of subsidence taking place and causing damage to the shafts and surface buildings. He (Mr. Black) contended that if the system were properly applied, there was not the slightest risk of such an occurrence. Mr. Riddell had stated that if he (Mr. Black) had given comparative figures of the cost of driving by the two methods, it would have been possible to judge whether the economical advantage claimed was real. He (Mr. Black) had apparently taken too much for granted in connexion with this matter, as he considered that the economy effected by the adoption of the system was so obvious to the practical mind that its support by figures was superfluous. In the system that he (Mr. Black) advocated, the output of coal obtained was very much greater than that yielded by the ordinary method, although the oncost charges were practically the same in both cases. Mr. Riddell had remarked that there was no difficulty in ventilating the narrow places when forming a shaft-pillar, and that the cost of brattice or air-tubes was a mere detail. He (Mr. Black) did not agree with those views, as his experience in the use of air-tubes when forming a shaft-pillar proved otherwise. Air-tubes were not to be compared with a roadway, either as an economical or as a satisfactory means of ventilating the workings. In the case of a large shaft-pillar the total length of air-tubes required was considerable, and he did not agree with Mr. Riddell that the cost of these was a mere detail.

He agreed with Mr. James Hamilton that it ought not to be

impossible to do away with shaft-pillars altogether in thin seams. The seam would no doubt require to be excavated in a very systematic manner, and the utmost care exercised in the packing of the goaf, in order to ensure that subsidence was uniform and regular.

The President (Mr. D. M. Mowat) had remarked that the extraction of 20 per cent. of the seam was quite an ordinary figure, and was usually accepted as good practice. He (Mr. Black) considered that the maximum percentage of coal that could be worked in a seam without causing subsidence was a question of great importance to mining engineers, as it appeared to him (Mr. Black) that our present knowledge of the subject was very vague. It was only logical to infer that if 20 per cent. could be worked in a 6-foot seam, at a depth of 200 fathoms, without causing subsidence, a greater percentage could be safely extracted in, say, a 2-foot seam at a depth of 50 fathoms, the nature of the strata being approximately the same in both cases. Much valuable information would be obtained on this point if the members of the Institute could be induced to state their experience.

Mr. William Smith (Dalmellington) had referred to the possibility of a serious leakage of air through the stowage from intake to return. He (Mr. Black) agreed with Mr. Smith that in some cases a leakage of air would be highly probable, unless some special means of making the stowage airtight were adopted. This was a matter which depended, not only upon the nature of the material available for packing, but also upon the extent to which the weighting of the nether roof took place. He would point out to Mr. Smith, however, that it would not always be necessary for the efficient ventilation of the mine to use each pair of roadways as an intake and return respectively. For example, in the case in which he (Mr. Black) had adopted the system advocated (which was shown in Fig. 2 in his paper), the top east level and the top west level were both discarded after the shaft-pillar had been formed. The two headings were now used as intakes and the bottom east and west levels as returns.

In reply to Mr. Robert McLaren, he had to state that the fact of his leaving a coal-pillar of 30 feet between the shafts and the point where longwall work commenced did not necessarily imply that he (Mr. Black) had no faith in the system which he advo-

cated. A slight movement of the nether roof which would be beneficial in the longwall work by assisting to consolidate the stowage might prove destructive to the shaft-lining. It was for that reason alone that he had suggested the leaving-in of a small pillar of solid coal next the shafts.

Mr. John Gibson (Kilmarnock) had stated that "as a matter of practice, the first point to consider in forming a shaft-pillar was the thickness of the surface, and this, he thought, Mr. Black had omitted." He (Mr. Black) considered that in the introduction to his paper he had made it sufficiently clear, even to the lay mind, that it was not his intention to discuss the method of determining the size of shaft-pillar that should be left in order to obtain security against subsidence, but to describe a method of forming a shaft-pillar in thin seams. Did Mr. Gibson not clearly comprehend from that statement that it was method, and not magnitude, that he (Mr. Black) was dealing with, and that his (Mr. Gibson's) contentions with regard to the nature and thickness of the surface had no bearing whatever on the remarks that he (Mr. Black) had made in his paper? Mr. Gibson also stated that "Mr. Black implied that he had driven these places at the rate of about 2 feet in the 24 hours." He (Mr. Black) repudiated that statement, because he had never implied anything of the kind. The total length of the three longwall places was about 210 feet, and the thickness of the seam worked was approximately 3 feet. Taking 30 cubic feet of coal to the ton, a simple calculation would show that the rate of advance was, with an output of 70 tons, $3\frac{1}{3}$ feet in the 24 hours. As a matter of fact, the measured rate of advance was about 8 yards per week, and this rate could have been considerably augmented but for reasons that were of no interest to the members. Mr. Gibson had also remarked that the most serious objection to the system was that it did not pay. That statement was no doubt due to his (Mr. Gibson's) wrongly-conceived notion that the adoption of the system made the dividend-earning stage more remote. It would appear that the comparatively slow rate of advance in the case that he (Mr. Black) had described had been accepted by Mr. Gibson as the maximum obtainable, and that he had not seen the possibilities of the system in their proper perspective. In order to show the possibilities of the system, he (Mr. Black) would ask Mr. Gibson to consider the formation of the shaft-pillar shown in

Fig. 1 of the paper. Assuming that the seam was 3 feet thick, that it was lying at a moderate inclination, and that the conditions were in every way suitable for the use of coal-cutting machines: then, to undercut and strip two 5-foot cuts of coal, and to brush the roads in each longwall place in the 24 hours, would not be doing anything more than was being done in several collieries with which he (Mr. Black) was acquainted. In fact, he had just completed the driving of a pair of dooks, by means of a bar coal-cutter, in which that rate of advance was maintained from start to finish. In the shaft-pillar under consideration the rate of advance of each longwall face would be 20 yards per week, and during this period the yield of coal would be 1,680 tons, which was equivalent to an output of 280 tons in the 24 hours.

Mr. J. Balfour Sneddon had asked whether he (Mr. Black) had been influenced in any way by observing the results of the method of working practised in his own district. In reply, he might state that it was the experience derived from working by that method that had led him to adopt it when forming shaft-pillars. In a 3-foot seam, at a depth of about 80 fathoms, he had driven three longwall places underneath valuable property through a large pillar of coal that had been left to protect it. Although the width of the face was 120 feet for some distance, and 90 feet for the remainder, there was not the slightest evidence of subsidence on the surface, which went to show that the absolute roof had not broken. He (Mr. Black) considered that thin seams underlying valuable property could be economically and safely worked by that method.

The President had stated that on the question of permanent advantage he did not like the driving of roadways in such a room-and-rance system alongside the ribside. He agreed with Mr. Mowat that some roofs would be liable to break off along the ribside, and that, in order to avoid roof trouble from this cause, the face should extend for a few yards beyond the off side of each roadway. By doing that the roof would break clear of the roadway, which would thus be maintained more easily.

The discussion of the paper was closed, and Mr. Black was awarded a cordial vote of thanks for his paper.

## DISCUSSION OF MR. HENRY BRIGGS'S PAPER ON "A METHOD FOR THE RAPID ESTIMATION OF OXYGEN AND BLACKDAMP IN THE AIR OF SAFETY-LAMP MINES."*

Mr. ROBERT MCLAREN (H.M. Inspector of Mines, Airdrie) said that it was rather a pity that Mr. Briggs had confined his attachment to one particular type of lamp. It might be possible, and, indeed, ought to be possible, for him to fit it to many of the other good types of lamps which were now being used by firemen, very few of whom, so far as he knew, were carrying the improved Gray lamp. The method of operation, as described on page 171, did not appear to be very clear. He did not think that it had struck many mining people that temperature had a great deal to do with the question of the determination of oxygen or of the height of a gas-cap in the mine. He had tried for caps very frequently, and his experience went to show that analysis of the same size of cap in the mine and in the laboratory disclosed the fact that the percentage in the laboratory test differed from that in the mine. There must, he felt, be a reason for that, which was, he thought, that in the mine there was a constant and unvarying temperature, whereas in the laboratory the temperature was variable and varying all the time. The device, he considered, would fail for the reason that it called upon the fireman to do two things when one might serve the purpose quite well. If the device was to serve any useful purpose, he was of opinion that it must be on simpler lines than those proposed. At the same time, he hoped that the attachment would not meet with the same fate as some of the other proposals and ideas that had been put before them within recent years. All sorts of ingenious devices in connexion with gas-caps, etc., had been laid before them, and where, he might ask, were they to-day? From a practical point of view he quite believed that Mr. Briggs's device would do all that was required. As Mr. Briggs had himself admitted, they could not expect the same detailed accuracy from the attachment as could be obtained from analysis, but for all practical purposes the instrument seemed capable of doing its work if only the firemen could be induced to use it. It was quite obvious that Mr. Briggs had spent much time in his endeavour to make his device success-

* *Trans. Inst. M. E.*, 1916, vol. li., page 169.

ful—and the table which accompanied the paper was really most valuable—but he (Mr. McLaren) feared that it could not be really successful unless it indicated to the firemen at a single glance how his places stood in relation both to firedamp and to oxygen.

Mr. Hugh Waddell (Tranent) wrote that he had gained some practical experience in the use of Mr. Briggs's device in the course of the tests made at St. Germains Collieries, and was surprised at the moderate claim put forward by Mr. Briggs for his apparatus. Although Mr. Briggs had introduced the device as one for the estimation of oxygen and blackdamp in the air of safety-lamp mines, it was, however, also capable of fulfilling these functions in naked-light mines. It might, therefore, be described as an apparatus for the detection of these gases in all classes of mines.

The state of perfection attained in Mr. Briggs's device was well worth the labour and energy that he had expended upon it. He had put into the hands of the mine fireman an apparatus that he could manipulate without possessing any expert or technical knowledge. It had no delicate parts about it likely to get out of order; the fireman would readily understand its principle and construction, and those who had been trained in the estimation of percentages of inflammable gas would not require any special training in its use.

Mr. Briggs had stated that it was unnecessary to use his apparatus in naked-light mines, as the practical utility of the Haldane tube made it applicable to this class of mine. In many naked-light mines in Scotland, however, the inspection by the fireman must necessarily and compulsorily be made with a safety-lamp, in terms of Section 64 (2) of the Coal Mines Act. It was obvious, therefore, that the Haldane tube could not be utilized to assist the fireman in such cases.

The device described by Mr. Briggs enabled the fireman not only to make a test for inflammable gas, but also to ascertain more readily than with the Haldane tube (in fact, in about half the time) the percentage of oxygen and blackdamp in the atmosphere. This allowed the fireman to carry out his duties more expeditiously and thoroughly, and gave him an apparatus which showed at once whether or not the mine air was in a fit state, according to the Mines Act, for men to work or to pass therein. He (Mr. Waddell) was satisfied that the device would

comply with all the claims made by the inventor on its behalf.

With reference to the readings taken by the Haldane tube, as recorded in Table IV. (page 182), he was surprised to find the values registered varied considerably. In the same atmosphere a much higher value could be obtained as the temperature of the tube increased. This was the first occasion on which he (Mr. Waddell) had practical experience in using the tube, and he wondered whether the readings obtained by other operators were more consistent under temperature variations.

The further discussion of the paper was adjourned.

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Mr. JAMES NISBET read the following paper on "The Sinking and Equipment of a Circular Shaft":—

# THE SINKING AND EQUIPMENT OF A CIRCULAR SHAFT.

By JAMES NISBET.

*Introduction.*—The writer does not claim that there is anything novel, or difficult, in connexion with the sinking about to be described. He, however, thinks that as circular shafts are not numerous in Scotland, the present paper describing some of the little details connected with such a sinking will be of interest, and, more particularly, to the younger members of the Institute.

The shaft was sunk at Dykehead Colliery, Larkhall, the owners of which are the Summerlee Iron Company, Limited. The colliery has been worked for over 50 years, during which time coal-getting has been confined to the upper seams. These seams have been worked by a day mine (forming the downcast), and by a rectangular shaft (forming the upcast), from both of which coal has been drawn. As the day mine referred to will shortly cease to be available for this purpose, it became necessary to sink another shaft, to serve as a downcast, by which the output might be maintained and some of the lower seams won.

The site of the shaft was chosen in regard to the existing and projected surface arrangements, and to its being suitable from its position to serve a main underground haulage-road, which has been driven in a predetermined direction. The surface overlying the metals is composed of sandy clay of considerable depth, and the surface barring of the previously-mentioned rectangular shaft has had to be repaired from time to time on account of its decay, and consequent bulging into the shaft. This movement was in each case inevitably accompanied by a sinking of the surrounding ground, which, more or less, disturbed the level of the bell-crank beams, and of the pit-mouth generally. It was, therefore, decided to make the new shaft circular, as being the stronger and more readily secured form, and to enclose its mouth in a foundation-block of concrete resting on the solid clay.

*The Sinking.*—The shaft was made 13½ feet in diameter; it is 426 feet deep, and is lined with brickwork throughout. Generally, the brick lining is 9 inches thick, but, at certain parts hereinafter mentioned, the thickness is greater. From the rockhead to the surface, a distance of 46 feet, the 9-inch brickwork is backed with concrete 12 inches thick, rammed solid, for the purpose of shutting off effectively the entrance of surface-water. A shaft of this diameter provides ample accommodation for two cages, each carrying two hutches end to end, and each hutch capable of holding 10 cwts. of coal. As the depth of the shaft is comparatively shallow, single-deck cages are sufficient to meet the capacity of the screening and washing plants.

The centre of the proposed shaft having been pegged off, marks were fixed at points not likely to be disturbed, from which intersecting lines could at any time be stretched so as to determine the centre, after excavation had commenced. Three of these marks were on a line passing through the centre of the pit on the proposed centre-line of the drum of the winding-engine.

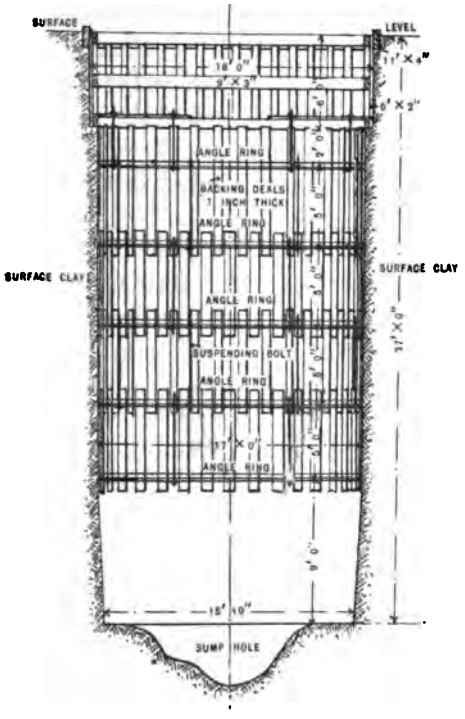
*Support of Surface Clay.*—A square frame, made from 11 by 4-inch white-pine planks on edge, and measuring 18 by 18 feet inside, was let into the surface, and levelled up. Each side of the square was equidistant from the centre, and two of them were parallel with the centre-line of the winding-engine drum. This frame was put in to mark the limits of a concrete surface foundation-block, and to form a guide and backing for the shoring for the support of the sides of the excavation, which was now commenced, and was cut down plumb from the inside of the frame. At a depth of about 3 feet, another frame, made from 9 by 3-inch planks on edge, and measuring outside 17 feet 8 inches by 17 feet 8 inches, was laid down on the bottom of the excavation concentric with the frame above.

Behind this frame, at close intervals all round the sides of the excavation, pieces of 6 by 2-inch battens, about 6 feet long, were entered on end, and the heads of them held back by a similar frame fixed at a higher level. As the excavation deepened, the battens were driven down, in order to guard against any slipping in of the sides. At a depth of about 6 feet from the surface, a third and similar frame was put in, to hold back the feet of the battens (Figs. 1 and 2).

The excavation was now reduced to a diameter of 17 feet,

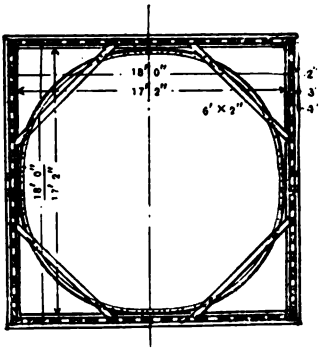
and the sinking of the circular shaft commenced. The sides of the shaft were supported through the surface clay and in soft metals, where met with, until the permanent lining was put in, by using angle-iron rings, behind which backing deals 1 inch thick were wedged against the sides of the shaft. These rings were built of 3 by 3 by ½-inch angle-iron, in four equal segments, curved to form a true circle of an outside measurement 15 feet 4 inches in diameter (Figs. 3 and 4).

FIG. 1.—SECTIONAL ELEVATION.




The segments were joined together with iron fishplates, measuring 3 by ⅝ by 21 inches in length, with four ⅝-inch bolts to each joint. This size of ring was used when sinking through metals, where the cutting was reduced to a diameter of 15½ feet.

FIG. 2.—PLAN.



FIGS. 1 AND 2.—TEMPORARY SUPPORT OF SURFACE EXCAVATION. SCALE, 12 FEET TO 1 INCH.

As used in the surface-clay, where, as already stated, the shaft was cut 17 feet in diameter, the rings were enlarged by introducing between each of the four joints a short piece of angle-iron 18 inches long, and by bolting up through long fishplates with seven bolts to each joint. Three of the bolts passed through the added piece of angle-iron, and held it in position.

The ring thus formed was not truly circular, but was near enough for the purpose intended, and its adoption made one set of rings serve. Holes were bored in the bottom flange of each segment for long-screwed bolts, screwed at both ends, whereby the rings were hung from supports or from one another (Figs. 1 to 4). By adjusting the nuts on these bolts, the rings were levelled up and hung at the desired distance apart—namely, from 3 to 5 feet.

The first ring was put in 2 feet below the point at which the circular sinking commenced. It was hung from battens supported on the bottom frame in the square-cut excavation. Others were placed at intervals, hung one from the other, as the sinking deepened through the clay. For the first 12 feet of the sinking, the excavated clay was cast out in stages to the surface. Thereafter, until a total depth of 148 feet was reached, a 3-ton steam crane, with a 65-foot jib, was used for the sinking.

This crane was fixed to one side in such a position that it would also serve for the erection of the pithead frame, and for handling the heavier portions of the permanent winding-engine, when being erected. Sinking kettles of the ordinary tipping type were used. Two of these were in service, except at the earlier stages.

When used for the sinking, the jib of the crane was raised to such an elevation that the end of it swung radially over the centre of the shaft. When winding *débris*, the kettle was raised to the necessary level above the surface, and the jib of the crane then swung round until the suspended kettle was vertically over a dirt bogie standing equidistant with the shaft from the crane. The kettle was then struck, and its contents tipped into the bogie, which was taken to the dirt tip while the kettle was being swung back and lowered into the shaft. On reaching the bottom, it was set down alongside another kettle that had been filled in the interval, the rope was then detached, and attached by a spring dog-hook to the full kettle, which was then in turn raised to the surface.

Every short distance, as the sinking progressed, radial measurements were taken from a central plumb-line, to ensure that the shaft was being sunk truly vertical and circular in form.

At this stage, from the nature of its suspension, the plumb-line had to be placed in position each time that measurements

were taken. To ensure that on each occasion it would be hung in exactly the same position, the following simple plan was adopted:—A piece of 4 by 4½-inch pitchpine slide was laid diametrically across the shaft, and its ends, which were marked, fitted into close-ended shoes fixed to the frame bounding the square excavation. The centre of the shaft was marked on this spar, and an auger-hole bored vertically through it at the mark. This hole was covered by a thin steel plate with a small hole in it, only large enough to admit the plumb-line. Before being screwed down, the plate was adjusted, so that the hole in it was exactly over the centre of the shaft. It was, therefore, only a matter of winding up the plumb-line, when no longer required, and lifting the spar out of its fixture and laying it aside, with the assurance that it could be replaced in exactly the same position when required. The plumb-bob was of cast-iron, cylindrical in shape, measured about 20 inches in length by 3¾ inches in diameter, and weighed about 60 pounds. It was turned true to ensure balance, had one end pointed, and the other flat. In the centre of the latter an eyebolt was screwed, to which the plumb-line was attached.

*Bricking-seat in Clay.*—At a depth of 37 feet from the surface, while the sinking was still in the surface clay, it was thought desirable to form the first bricking-seat, and to put in the permanent lining of this portion of the shaft. The last 6 feet of the cutting had gradually been reduced from 17 feet to 15 feet 10 inches in diameter.

The bottom was levelled up round the sides of the shaft, and some bricks and mortar lowered. The central plumb-line was then run down, a sump-hole in the bottom allowing the plumb-bob to hang free, well below the level of the bricking-seat.

Bricks, in pairs, placed radially and exactly 6 feet 9 inches from the central plumb-line, were now bedded in cement-mortar, at intervals of about 3 feet, all round the circumference of the shaft, and the spaces between these thereafter filled in to template. The complete circle thus made formed the foundation upon which the brickwork was built.

When at a height of about 3 feet, the circularity of the shaft was checked by a measuring stick from the plumb-line, and eight plumbing marks were put on the brickwork at equal distances round the shaft. As the brickwork rose, plumbings were taken

Fig. 3.—Section.

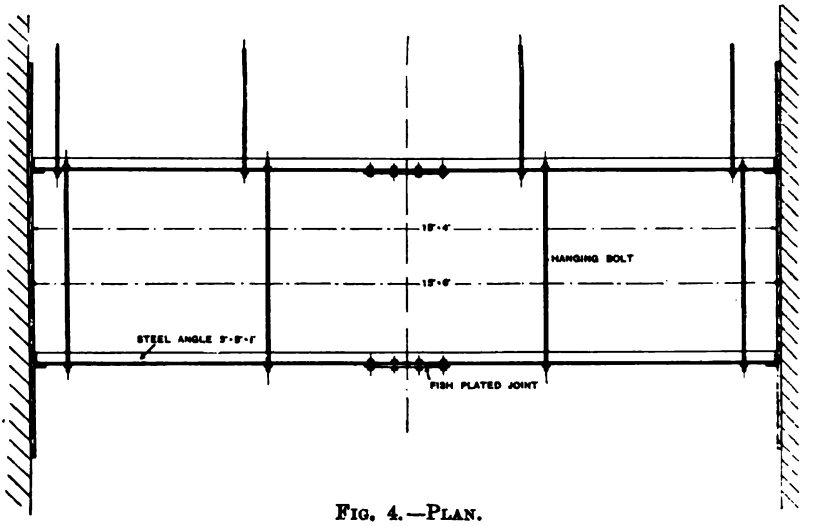
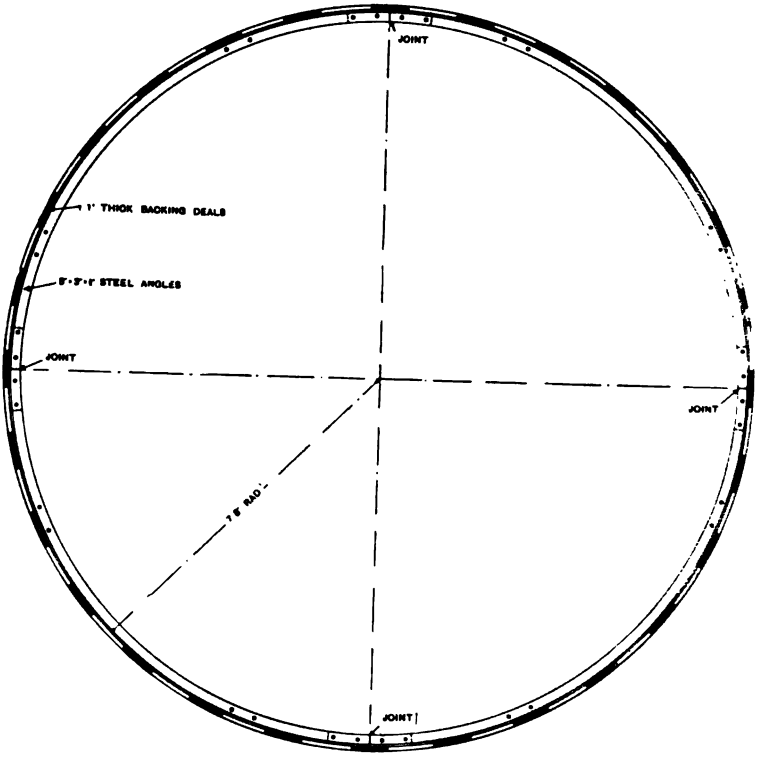



Fig. 4.—Plan.




Figs. 3 and 4.—Ring Used for Temporary Support of Excavations.
Scale, 4 feet to 1 inch.

over these marks, and the portion between each two plumbings built to template. The plumbings were checked every 8 feet, which corresponded with every alternate shift of the bricking scaffold. The first 6 feet of the brickwork was built solid against the tapered sides, thus corking itself into the clay. From that point, right up to the surface level, the brickwork is 9 inches thick, and is filled in behind with cement-concrete, rammed hard against the sides. As the walling progressed, the temporary lining of the shaft was taken out.

When the brick lining had been carried up to the level of the surface, concrete was filled in behind. The timber supporting the sides of the square excavation was gradually removed, and the whole space filled with concrete, which was finished off level and flush with the top of the brickwork.

The bricks used for the lining were made of blaes containing a small admixture of fireclay. They are 9 inches long, tapered from $4\frac{3}{4}$ inches to $4\frac{1}{4}$ inches in breadth, and $3\frac{1}{2}$ inches thick, and are all built headers with the narrow end facing into the shaft. Down one side of the shaft, at intervals of 4 feet, a line of oak blocks was built into the lining, to provide a means of fixing a column of pipes, in case these were required. The mortar was composed of 1 part of cement to 2 parts of clean sharp sand, and the concrete mixture consisted of 1 part of cement, 2 of sand, and 4 of broken brick.

The bricks were loaded into the kettle at a point which could be reached by the jib of the crane, and thereafter lowered and emptied—on to the bottom at the commencement of the bricking, and on to the bricking scaffold when that was in use. The ashes used for packing, as explained later, were also lowered in the kettle and tipped on to the scaffold, from which they were shovelled in behind the brick lining.

The mortar and cement-concrete were each mixed on the surface, and filled into strong shallow boxes about $3\frac{1}{2}$ feet square and 9 inches deep, provided with a door at one side, and a lug at each of the four corners for the attachment of the suspension chains. Two of these boxes were provided, so that while one box of mortar was in the bottom, out of which the bricklayers worked, the other was being got ready at the top. When the concrete backing was being filled in, the box was lowered, and the front or door side of it rested on the top of the brickwork. The

front chains were then detached, the door taken out, and the back end of the box raised gradually until the contents slid out into position behind the brickwork.

*Bricking Scaffold.*—The bricking scaffold (Figs. 5 to 10) was 13 feet in diameter. The body of it was made of 9 by

FIG. 5.—PLAN.

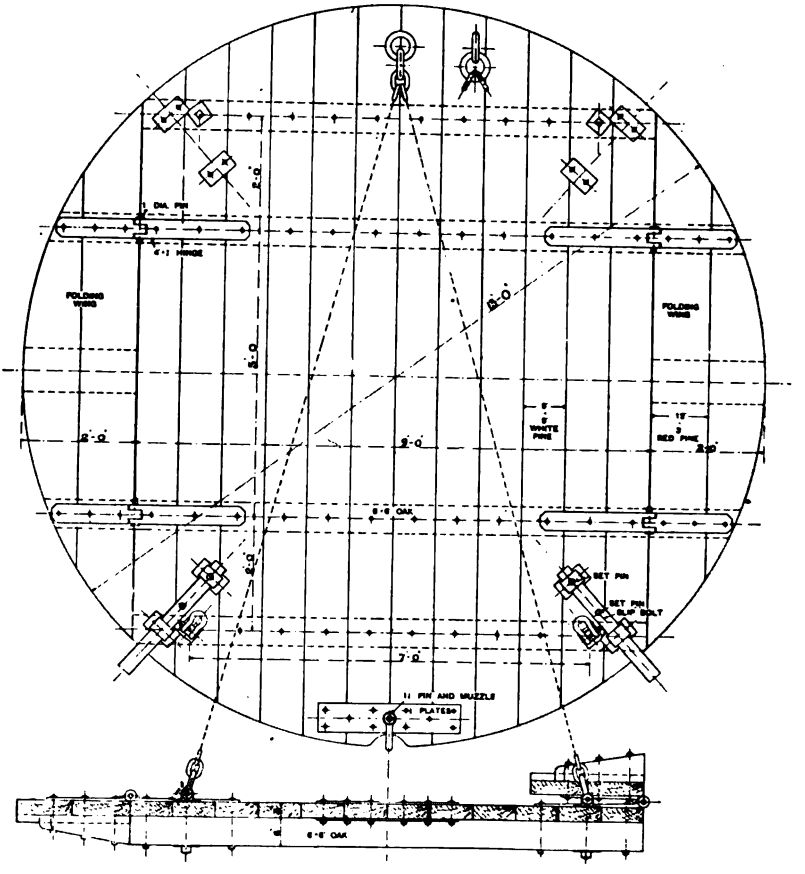



FIG. 6.—SECTION.

FIGS. 5 AND 6.—BRICKING SCAFFOLD. SCALE, 3½ FEET TO 1 INCH.

3-inch white-pine planks bolted to 6-inch square oak beams with ⅝-inch bolts. On two of its sides a 2-foot segment was made to fold in on strong iron hinges, well secured to the main portion. These wings were made from 12 by 3-inch red-pine planks, bolted across 6-inch square pieces of oak, and were

strengthened in the centre by a 9 by 1½-inch white-pine doubling underneath. The scaffold was suspended by four ¾-inch short-link chains 12½ feet long, attached by muzzle and pin to eye-bolts passing down through the outside oak beams. These eye-bolts were fixed diametrically opposite, and were 7 feet apart on the line of the beam, and 9 feet apart across the same. The scaffold was provided with four strong slip-bolts, each 3 inches square

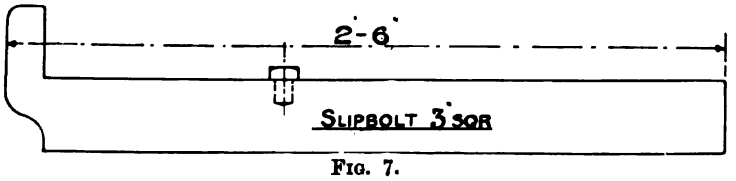



FIG. 7.

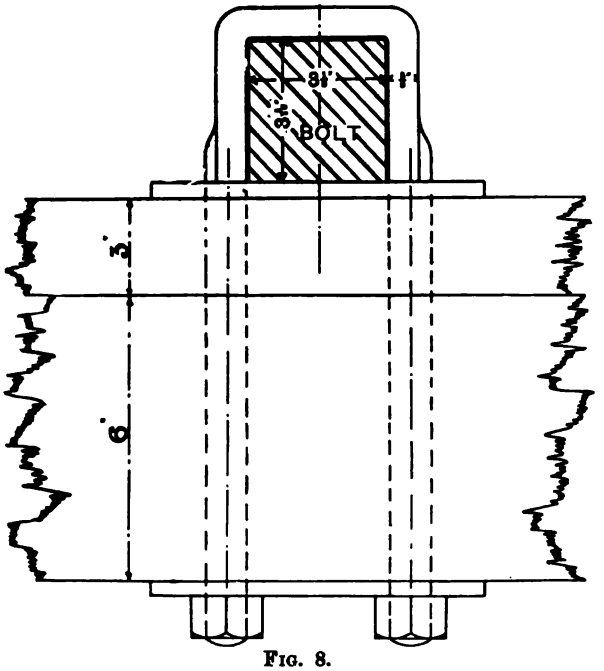



FIG. 8.

and 2½ feet long, sliding in 3 by ⅝-inch keepers, the outer of which was also bolted down through the oak beam.

The bolts, when fully extended, projected 6¼ inches beyond the edge of the scaffold. Between the outer and the inner keeper, a ¾-inch set-pin was screwed into the body of the bolt in order to adjust the travel of it, and to prevent it from falling out when the scaffold was tilted or hung up in the shaft. Another set-pin,

screwed down through the inner keeper, provided the means of fixing the bolt in an extended or withdrawn position, as required.

A strong muzzle was fixed to the edge of the scaffold, midway between the wings, by which, with the wings folded, it could be hung up on edge close in against the sides of the shaft. The scaffold, when not required, was lifted out and laid aside on the surface up to the time when the mouth of the shaft was covered over.

Fig. 9.

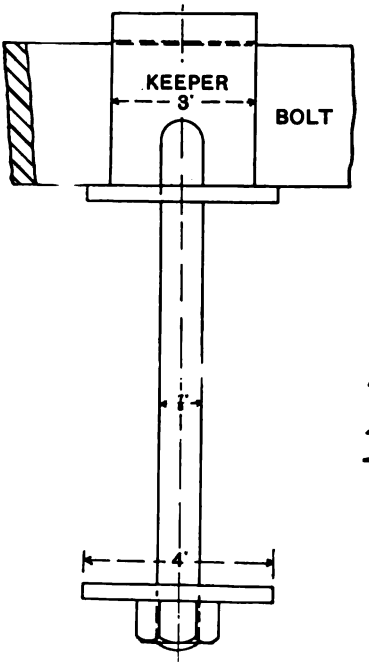
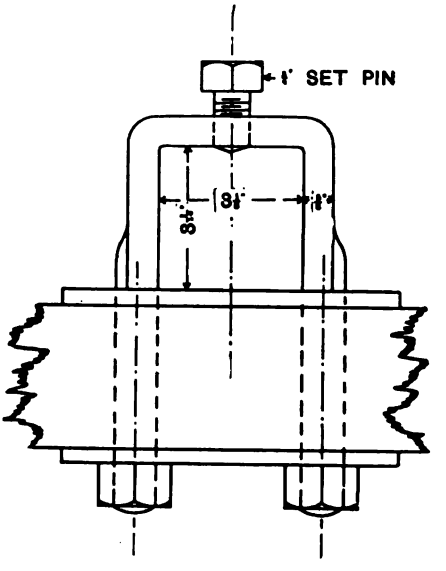



Fig. 10.




Figs. 7 to 10.—Details of Slip-bolt. Scale, 4 inches to 1 inch.

The first 4 feet or so of the lining having been built, the scaffold was lifted into and lowered down the shaft, and rested on its slip-bolts on the top of the brickwork. The chains were detached from the scaffold and taken to the surface, thus leaving a clear platform for the men to go on with their work. The chains were brought down again and re-attached, when the scaffold had to be lifted, which was done in stages of about 4 feet. When "eased" off its rest, the bolts were withdrawn, and the holes which had been occupied by them were filled up. The scaffold was there-

after lifted and again rested on the top of the brickwork, and the process repeated as before.

On the completion of the formation of the surface foundation-block, sinking was resumed. Plumb-strings, hung from the face of the brickwork above, made it easy for measurements to be taken to ensure that the sinking was circular and to the proper size. The excavation was gradually widened out to 17 feet in diameter, and continued at that size until the sinking had reached the bottom of the surface clay, at a depth of 46 feet from the surface, and passed into soft fireclay, 5 feet thick, lying on the top of sandstone rock. This portion of the sinking was temporarily supported by rings and backing deals, as previously described. The excavation was reduced to 15½ feet in diameter from the bottom of the clay, and continued at that size until about 6 feet above where it was decided to found the next bricking-seat, when the shaft was widened out and sunk 16 feet in diameter until a bed of fakey fireclay, 37 feet below the bricking-seat above, was reached.

*Bricking-seat in Metals.*—A sump-hole having been made, the central plumb-line was run down, and bricking commenced in the same way as for the previous stage. As the inclination of the strata was slight, no special preparation was required for the seat. The brickwork was brought up from the low side and levelled all round. The first 6 feet was made 14 inches thick, and was built solid against the metals. From that point upwards the lining was 9 inches thick. As the brickwork rose, and until the bottom of the surface clay was reached, ashes were packed in behind. Thereafter cement-concrete formed the backing for the completion of the stage.

As before, and in each successive stage, the timber and rings temporarily supporting the sides were withdrawn as the brickwork progressed. When the latter approached the bottom of the upper length, the whole of its seat was cut away and the brickwork joined up with 9-inch work. No slipping of the upper length was observed.

In starting away the next stage of the sinking, the brickwork was left sitting on a ledge of strata gradually tapering out to the sides of the shaft (Fig. 11). This stage of the sinking was, for the greater part, in soft strata, and

the soft "veese" of a fault passed through the shaft. A little water was got, and the sides were inclined to "make." These were temporarily supported, and sinking was carried on until the fault had crossed the shaft and a fairly good bricking-seat was reached. By that time the unlined portion of the shaft measured 44 feet, or 7 feet more than either of the two previous stages. In order to guard against any possible slipping of the brickwork when sinking was resumed, the bottom 10 feet of the lining was built solid against the sides, and tapered from 9 inches at the bottom to 14 inches at the top. Gutters were left behind the brickwork, by which the water present could find its way through "weeping holes" at the bottom into the shaft. The remaining length of the lining was 9 inches thick, and was backed with 3 inches of ashes, as before. Junction was made with the brickwork above by gradually cutting away sufficient of the strata forming the bricking-seat to allow of lining at least 4½ inches thick to be put in to join up (Fig. 11). Any necessary brickwork was also cut away from the bottom of the upper stage, so as to allow of a neat and level joint being made.

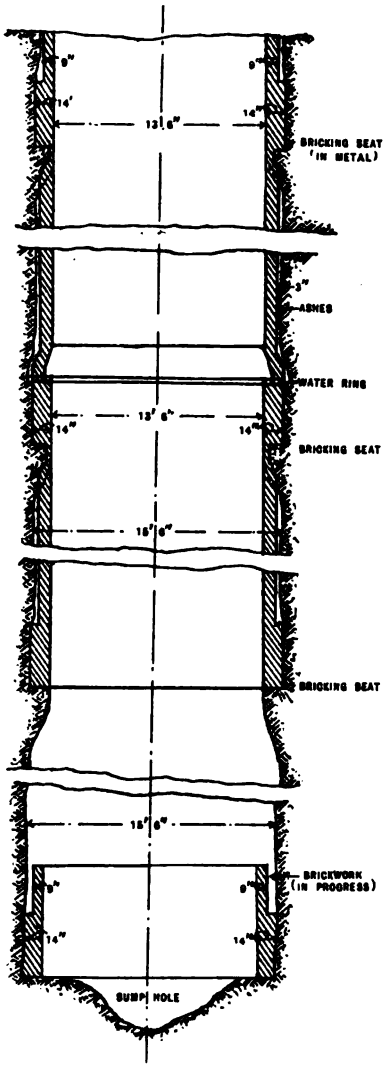



FIG. 11.—GENERAL SECTION OF SHAFT. SCALE, 12 FEET TO 1 INCH.

It may be here noted that there are various factors which, to some extent, govern the length of a bricking stage. The nature of the metals passed through is a deciding factor as to

how far it is judicious to continue the sinking without putting in the permanent lining of the shaft. Further, it is desirable to secure a satisfactory foundation for the brickwork—not too soft, for obvious reasons, nor too hard, as that would entail excessive hewing when joining up the next length of brickwork. Again, unless the sinkers are also competent bricklayers, the usual practice is to do the bricking during the week-end. This method allows of the sinkers working full time, and better ensures that bricklayers employed during the rest of the week on other jobs can be got for the work. In the sinking now being described, the bricking stages varied from 26 to 50 feet in length, and, in most cases, it was possible to complete the lining over the week-end.

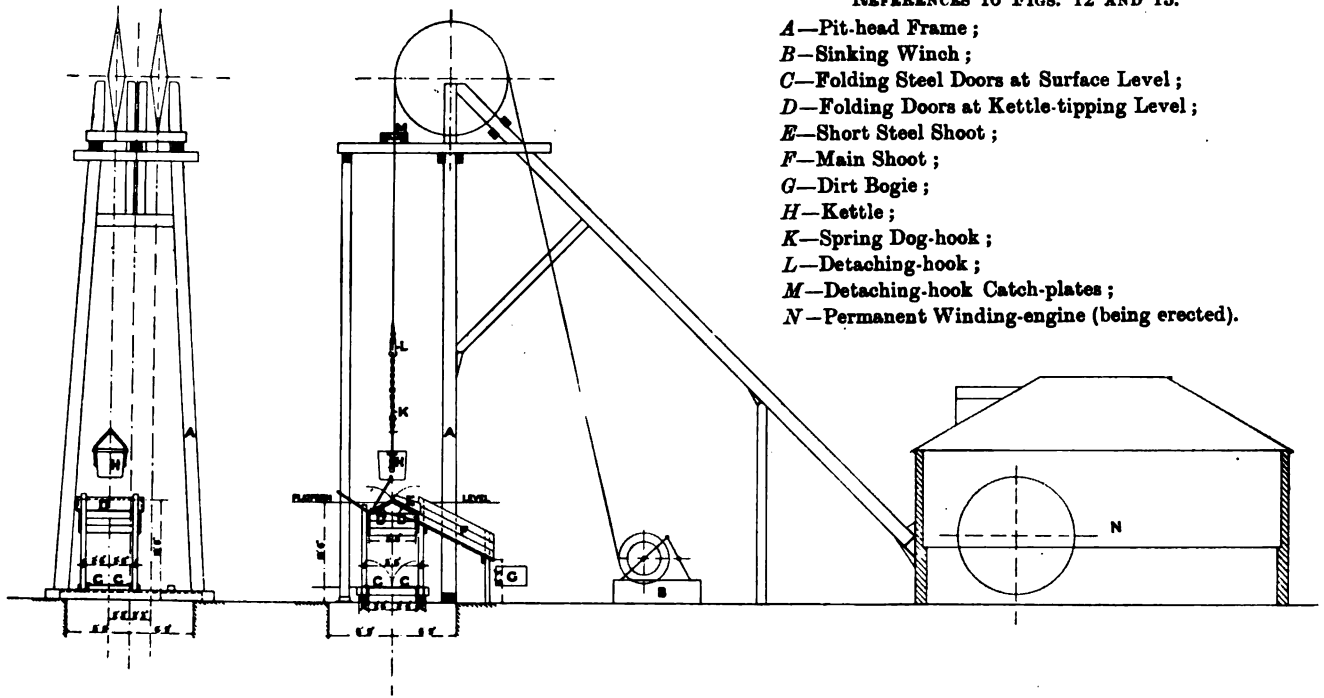
A further length of 30 feet having been sunk and lined, by the use of the steam crane, sinking was temporarily stopped until the permanent pithead frame and pulleys had been erected, a steam winch fitted up to replace the crane, and a kettle strike placed over the mouth of the shaft. The pithead frame is of timber, and was made 55 feet high to the centre of the pulleys, in order to provide adequate height for the adoption of double-deck cages if these should at some future date be required. The pulleys are 12 feet in diameter, and are placed 4½ feet apart.

The steam winch had 8 by 14-inch cylinders, and was geared 44 to 1. The drum was 5 feet in diameter, and 3¼ feet wide. A special patent improved steel-wire non-rotating sinking-rope 3 inches in circumference was used, and a 3-ton detaching-hook was provided.

Before the kettle strike could be erected, and so long as it was in use, the bricking scaffold, which hitherto, as previously mentioned, had been swung out and laid down on the surface when not required, had to be hung in the shaft.

*Kettle Strike.*—The strike was built centrally over one of the proposed cage spaces in the shaft. Two pitchpine beams, 12 inches broad by 9 inches deep, were laid across the shaft, equidistant from the centre, and 5 feet apart, so as to form the foundation for the structure. Between these, the folded bricking scaffold was lowered on edge, and hung as close as possible to the side of the shaft from a beam resting on the two beams previously mentioned.

FIG. 12.—FRONT ELEVATION. FIG. 13.—SIDE ELEVATION.




REFERENCES TO FIGS. 12 AND 13.

*A*—Pit-head Frame;
*B*—Sinking Winch;
*C*—Folding Steel Doors at Surface Level;
*D*—Folding Doors at Kettle-tipping Level;
*E*—Short Steel Shoot;
*F*—Main Shoot;
*G*—Dirt Bogie;
*H*—Kettle;
*K*—Spring Dog-hook;
*L*—Detaching-hook;
*M*—Detaching-hook Catch-plates;
*N*—Permanent Winding-engine (being erected).

FIGS. 12 AND 13.—GENERAL ARRANGEMENT AT SURFACE WHEN SINKING. SCALE, 20 FEET TO 1 INCH.

Two corner posts, measuring 6 by 6 inches in section, and placed 5 feet apart, were morticed into each sole beam, in order to form the framework for the necessary boxing. Around these the mouth of the shaft was covered in. Hinged steel doors, $\frac{3}{8}$ inch thick, were fitted to close on sides 9 inches deep, carried on the sole beams. Half of a circular opening 2 feet 9 inches in diameter (just large enough to receive the bottom of the sinking kettle up to the trunnions) was cut in each door, and provision was also made on the edge of the doors for their closing round the kettle-rider guide-ropes. Two eye-bolts were placed near the edge of each door, from which chains passed over pulleys fixed on the vertical posts, and carried balance-weights. This arrangement facilitated the opening and shutting of the doors. Angle-iron rails, hinged just clear of the doors on the off-side of the shoot, and long enough to span both doors, made it possible to run a bogie into position vertically under the winding-rope.

About 6 feet above the level of the steel doors a rectangular box, measuring 5 by 6 feet inside, was formed by bolting 9 by 3-inch planks to the vertical posts. This box was fitted with strong hinged doors, resting on side cheeks and meeting at an inclination of 1 in 2. The sides of the box were stiffened by steel plates. A crank and connecting-rod arrangement, operated by a handle fixed to one of the doors, provided the means of opening and closing the same. This operation was assisted by a balance-weight suspended from an overhanging lever. On the door, on the tipping side, a short steel shoot was bolted to guide the contents of the kettle into a main shoot and thence to the dirt bogie. A large shallow cesspool, connected to a drain, was formed under the bogie road, in front of the shoot, to receive any water filled with the *débris* or otherwise brought to the surface.

The pitheadman's platform was made level with the top of the box. A stair provided a means of communication with it and the ground level. Figs. 12 and 13 show the general arrangement.

When these operations had been completed, sinking was resumed. The workmen entered and left the shaft from the lower level, and from that level tools and material were sent down.

When the kettle was being loaded or unloaded in position there, the bottom of it was lowered into the circular opening in the closed doors, thus effectively preventing the possibility of anything accidentally falling into the shaft.

Bricks and ashes were filled into the kettle and mortar into boxes clear of the sinking, but convenient thereto, and conveyed on a low bogie to the shaft. The empty kettle or box, on reaching the surface, was rested on another bogie, which had been run into position over the closed doors. It was then detached from the rope, and the bogie withdrawn. The loaded bogie was then run in, the load picked up, the empty bogie withdrawn, the doors opened, and the load lowered down the shaft.

*Débris* was tipped and water discharged at the upper level. When these materials were being drawn, the steel doors stood open and effectively fenced two sides of the opening into the shaft. Wooden spars, fixed to the corner posts, provided the necessary protection on the other two sides. The upper doors were kept closed until the kettle or water-barrel approached the surface. By observing a mark on the winding-rope, the pithead-man knew when to open the doors for its passage. The doors were thereafter closed, and the *débris* or water discharged into the shoot. The doors were again opened for the kettle or barrel to be lowered into the shaft, and closed again as soon as it had passed clear.

Each stage of the sinking and lining was carried out as described. The bottom 4 to 6 feet of each length of brickwork was built solid against the sides, and was 14 inches thick. The remainder was carried up 9 inches thick, except where a junction was made with the brickwork above. There, the last three or four courses were from 9 to 4½ inches thick, depending on the hardness of the strata that formed the seat to the brickwork above, and on the amount of necessary hewing.

It was only when about to commence each length of brickwork, and at intervals during the building of it, that the centre plumb-line was run down. The temporary fixture for the plumb-line had to be abandoned when the kettle strike was erected. The wire was thereafter passed over a small pulley mounted on a piece of batten, which was hinged opposite one side and at the level of the steel doors. On the doors being opened, the pulley could be swung over into position, so that the wire passing over it was exactly in the centre of the shaft.

Little water was met with in the sinking, and at no time did it exceed 8 gallons per minute. It could therefore be dealt

FIG. 14.—SECTION.

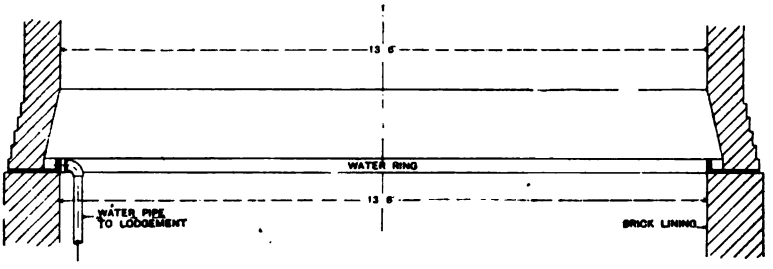
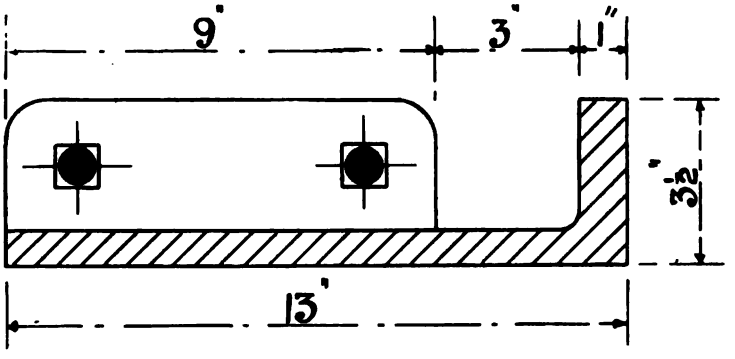



FIG. 15.—ENLARGED SECTION OF RING.




FIGS. 14 AND 15.—DETAILS OF WATER-RING. SCALE, 4 FEET TO 1 INCH.

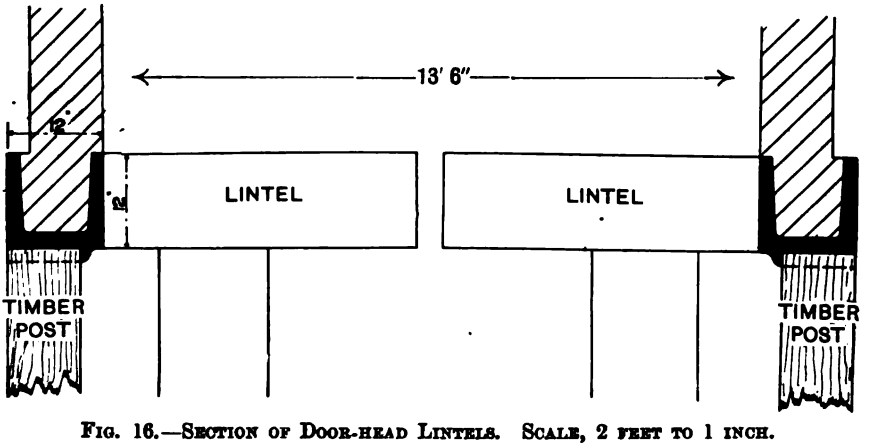



FIG. 16.—SECTION OF DOOR-HEAD LINTELS. SCALE, 2 FEET TO 1 INCH.

with by the kettle or water-barrel. A sump-hole in the bottom made the necessary lodgment from which the water could be

filled out and kept below the level of the bricking-seat when building was being commenced.

*Water-rings.*—Water-rings, to catch water finding its way down through the ashes behind the lining, or trickling down the face of the brickwork, were formed at various levels in the shaft. Where these were made, the sides were widened out to about 16 feet in diameter. Solid brick lining was brought up to the required level, and a cast-iron ring carefully levelled and bedded thereon. The ring was built of six flanged segments bolted together on planed joints to form a circle 13½ feet in inside diameter (Figs. 14 and 15). The ring is 13 inches broad and ¾ inch thick on the sole, and the flange 3½ inches deep and 1 inch thick. Brickwork was built on the top of the ring, leaving a clear annular space 3 inches wide all round for water. The brickwork was gradually overhung so that it measured 13½ feet in diameter, and coincided with the plumb of the walling, at a height of about 26 inches above the ring (Figs. 11 and 14). Special bricks were provided for this part of the work. These, in addition to being tapered on the sides, were splayed on the narrow end.

In the flange of one of the segments of each ring a hole 2 inches in diameter is provided, from which tubes are led to convey the water collected to a lodgment, which is drained by pumps in the old shaft.

The bricking scaffold was hung to each ring in turn by a grab over the flange, when not required for the lining of the shaft, thus minimizing the distance through which it had to be raised when bricking was stopped, or lowered when it was again commenced.

*Doorhead Lintels.*—In the course of the sinking the shaft passed through three seams of coal worked from the old pit. Although it was not intended to wind coal from these levels, connexion was made at each seam. The brick lining at each of these entrances to the shaft was built 18 inches thick, and at each an opening 9 feet wide and about 6 high was formed, in order to provide access to either cage when desired. The brickwork above each opening is carried on a strong channel-section cast-iron lintel, measuring 12 inches in breadth by 12 in depth, and curved to the circle of the shaft (Fig. 16). The brickwork, for a distance

of from 8 to 10 feet above the level of the lintel, is built solid against the sides. The lintel is steadied and strengthened by a stout timber post set underneath its centre. The bottom of the post rests on a timber sole, curved to the circle of the shaft, and the top is fitted into a pocket cast on the underside of the lintel.

No special provision had to be made for the ventilation of the shaft. As already mentioned, the shaft made connexion with three working seams, the upper one being reached at a depth of only 234 feet from the surface. Between it and the lower seam

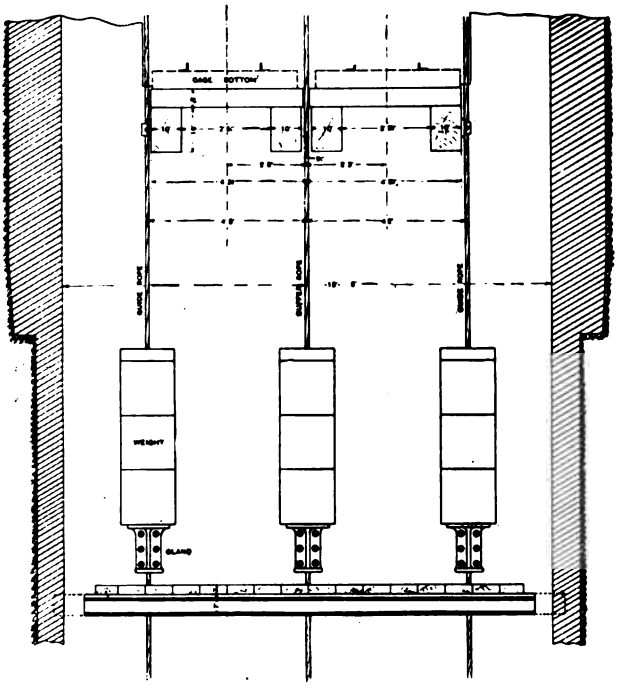


FIG. 17.—CROSS-SECTION OF CAGE-SEAT AND ROPE-WEIGHTING SCAFFOLD. SCALE, 5⅓ FEET TO 1 INCH.

a blind pit had, at an earlier period, been put up for ventilation purposes, in the position of the new shaft. This simplified the ventilation of the sinking. The shaft was lit up by electric light.

No mention has been made of the tools used by the sinkers, as these were similar to those required for the sinking of a rectangular shaft.

Having regard to the times, and the need for an increased output of coal, sinking was stopped when the shaft had reached a total depth of 426 feet from the surface. While it was originally

proposed to carry the sinking deeper, it was not intended, in the meantime, to wind from a lower level than 330 feet. At that level the pit went down on a back mine which had previously been driven across a fault to, and a short distance beyond, the site of the shaft. Before the shaft was lined at this point, the sides of the mine were widened out to the width of the proposed landing for a distance of about 20 feet on both sides of the shaft, so as to avoid the possibility of damage to the brickwork from blasting operations. The bricking-seat was situated 7 feet below

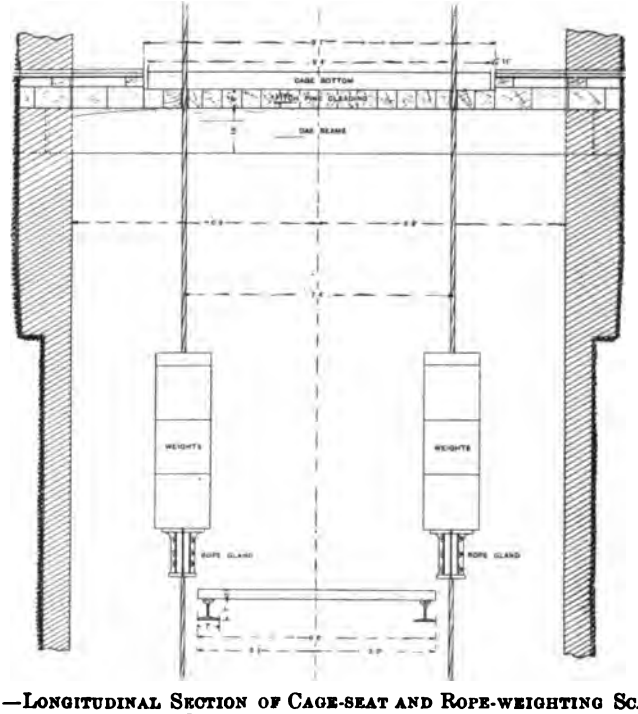



FIG. 18.—LONGITUDINAL SECTION OF CAGE-SEAT AND ROPE-WEIGHTING SCAFFOLD. SCALE, 5⅓ FEET TO 1 INCH.

the level of the landing, and from that point, up to the level of the door-heads, the lining was built 18 inches thick. An opening, 9 feet wide and 9 feet high, was formed on each side of the shaft to the underside of a cast-iron lintel carrying the brickwork above.

This mine was in line with the centre one of three parallel longwall dook-roads, each 50 feet apart, which had been driven from the old pit, in a virgin seam, for a distance of well over a mile, in order to develop a large area of coal to be won by the

new shaft. It may be of interest to remark, in passing, that the 50-yard wall was cut by a 5-foot disc coal-cutter, and that the rate of travel of the face averaged 400 yards per annum. The road mentioned is the haulage-road referred to in the opening part of the paper.

*Permanent Fittings.*—During the sinking operations, the permanent winding-engines had been erected. These consist of a pair of coupled engines, with cylinders 22 inches in diameter by

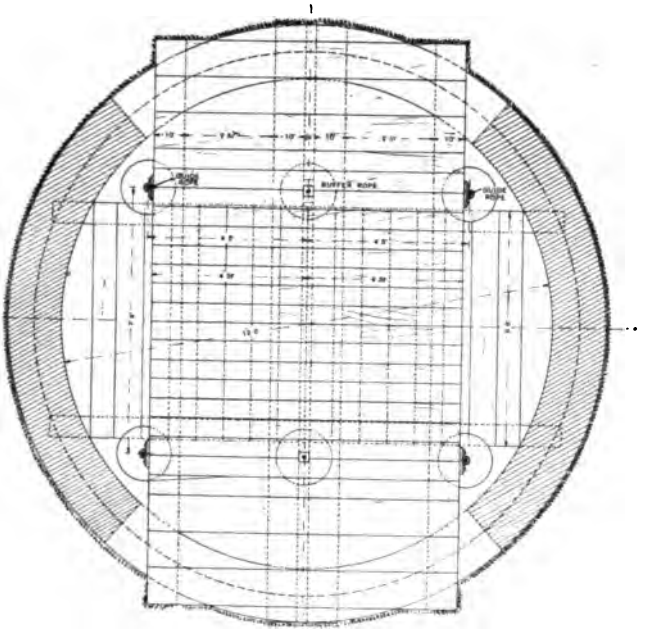


FIG. 19.—PLAN OF CAGE-SEAT AND ROPE-WEIGHTING SCAFFOLD. SCALE, 5⅛ FEET TO 1 INCH.

5 feet stroke, and a drum 12 feet 3 inches in diameter, working on a boiler pressure of 65 pounds per square inch. The pithead scaffold had also been erected and connected with the screening plant. The forming of the pit-bottom, and the putting in of the permanent fittings of the shaft, were therefore all that was required to equip the shaft for drawing coal.

The kettle-strike was cleared away, and arrangements were made for putting the cages and guide-ropes into the shaft.

A scaffold was put across the shaft 12 feet below the level of the proposed cage-seat beams, to form a platform from which the guide-ropes and buffer-ropes could be weighted. It was made of

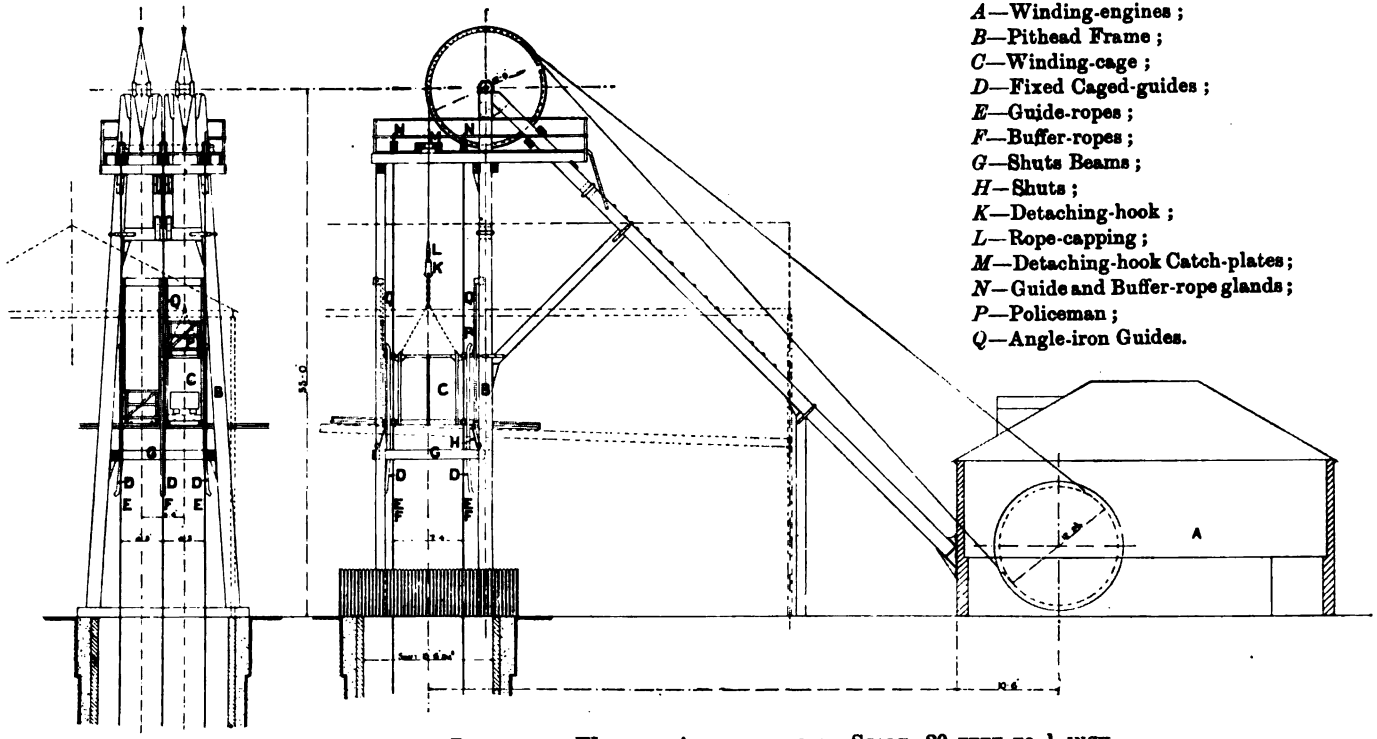
9 by 3-inch planks carried on 7 by 7-inch tramrail girders built into the sides of the shaft. The planks are bolted down with ⅝-inch bolts, which pass through holes in the sole of each girder. The girders are parallel, 5 feet 4 inches apart, and each of them is 5 inches inside of a line through the centres of the adjoining ropes (Figs. 17 to 19).

The bricking scaffold (which was carried on its bolts shot out into holes in the brick lining) was used when placing and building in the girders. Its chains, in the meantime, were on the surface. After the girders had been fixed in position, the bricking scaffold had to be brought up through between them, before the cleading was put on. This operation was carried out in the following manner:—Four pieces of the cleading were put across the girders, close to that side of the shaft which was farthest away from the rope. The scaffold chains, which hung from the winding-rope, were then brought down with the kettle and attached to the scaffold. The latter was now "eased" off its bolts, and, on these being withdrawn, it was lowered a little, and the holes in the brickwork filled up.

After this was done, the scaffold was lifted up as close to the girders as its chains in between the same would permit. A short sling-chain was now hung from one of the girders, and connected to the "hanging" muzzle on the edge of the scaffold. At this stage, the kettle and scaffold were both hanging on the rope—the former centrally between the chains of the latter. The wings of the scaffold having been folded in, the men got into the kettle, which was then slowly lowered until the weight of the scaffold had been transferred from the rope to the girder sling. The outside chains swung clear of the kettle as it was lowered. When the scaffold had reached a vertical position, and its four chains had become slack, the latter were detached from the rope and allowed to hang from the scaffold down the shaft. The kettle was then raised, and a chain attachment made between the scaffold muzzle and the rope, which now took the load. A man, standing on the partly-clad girder scaffold, disconnected the slackened sling-chain, and then guided the kettle and bricking scaffold up through between the girders, above which the scaffold was now hung, from a sling round a beam, and the rope detached. The girder platform was then completed.

*Cage Seat.*—The cage seat (Figs. 17, 18, and 19) is formed of four oak beams, each 10 inches broad and 15 inches deep,

FIG. 20.—FRONT ELEVATION. FIG. 21.—SIDE ELEVATION.




REFERENCES TO FIGS. 20 AND 21.

*A*—Winding-engines;
*B*—Pithead Frame;
*C*—Winding-cage;
*D*—Fixed Caged-guides;
*E*—Guide-ropes;
*F*—Buffer-ropes;
*G*—Shuts Beams;
*H*—Shuts;
*K*—Detaching-hook;
*L*—Rope-capping;
*M*—Detaching-hook Catch-plates;
*N*—Guide and Buffer-rope glands;
*P*—Policeman;
*Q*—Angle-iron Guides.

FIGS. 20 AND 21.—PERMANENT WINDING ARRANGEMENTS. SCALE, 20 FEET TO 1 INCH.

recessed into the brick lining, laid truly level, and covered over with pitchpine cleading 6 inches thick. Holes are countersunk in the latter, in the required position, to receive the heads of the cage-bottom bolts when the cage lands on the seat. Holes were also made in the cleading for the buffer-ropes to pass through. The two inner beams are placed 3½ inches apart, and are equidistant from the centre of the shaft. A distance of 2 feet 5⅝ inches separates each inner and outer beam respectively. The beams, so placed, provide 1 inch of clearance in each case between them and the hanging guide and buffer-ropes. When these beams, and also the girders and doorhead lintels previously referred to were being placed, a plumb-line was hung down either side of the shaft on the centre-line of the winding-engine drum. Measurements were carefully taken from these plumb-lines, so as to ensure accuracy of position of the work. When the recesses for the beams were being prepared, and when the latter were being placed in position, the bricking scaffold was again brought into service.

*Guide-ropes.*—The guide-ropes and buffer-ropes were now hung in position in the shaft. There are four guide-ropes—two to each cage—and two buffer-ropes. The ropes are each 450 feet long, and are constructed of mild-steel rods (six over one). The guide-ropes are 1¼ inches in diameter, and weigh 19⅔ pounds per fathom. The buffer-ropes are 1½ inches in diameter, and weigh 27⅔ pounds per fathom.

The buffer-ropes are hung equidistant from the centre of the shaft, in the centre-line of the engine-drum, and their centres are 7 feet 4 inches apart. Each of them is exactly opposite, equidistant from, and in line with two of the guide-ropes, which, centre to centre, are 8 feet 10 inches apart.

The ropes are each suspended from cast-iron glands, carefully placed in position, and bolted down to 6 by 12-inch beams resting on the pithead-frame crowns (Figs. 20 and 21). Each rope is loaded with cast-iron weights carried on a similar gland, which is fixed to the rope, below the cage-seat at the bottom landing (Figs. 17 to 19). Three weights, each weighing 10 cwts. and fitting one into the other, are carried by each rope. These are surmounted by a locking cap so as to retain them in position. Figs. 22 to 26 show the details of the glands and weights.

The ropes were placed in position in the following manner:—

A line from the centre of the engine-drum was stretched across the centre of the shaft. Another line was laid off at right-angles, also passing through the centre of the shaft. Careful plumbings from these lines allowed of marks being made on the crowns overhead, from which it was easy to measure and fix the exact position to be occupied by each rope and its carrying gland. These having been marked, each rope, in turn, was put on a reel, its end attached to that of the sinking-winch rope, and then coiled on the drum. The outside end of the rope was passed over the pithead pulley and the rope lowered down the shaft. The end was guided past the cage-seat and the girder scaffold below. In the case of a buffer-rope, the end had also to be guided down between the cage-seat beams. Lowering stopped when a sufficient length of the rope was still left above the level of the hanging-beams to reach the position to be taken up by the rope. The rope was then hung on a temporary gland at the pithead level and disconnected from the winch-rope. The freed end was now carefully brought down between the catch-plate beams, taken over, and glanded approximately in its position. Any adjustment required was easily obtained by tapping the gland to one or the other side. The rope was now seized well down and eased up to allow of the temporary gland being taken off, after which the slack was lowered, and the rope assumed its permanent position in the shaft.

The ropes having been thus hung in position, each was loaded with weights to the extent previously mentioned. Each weight is tapped for eye-bolts, by which it was slung from the winch-rope, lowered down the shaft, and placed in position on the rope.

Pieces of oak were wedged between the cage-seat centre beams, 1 inch clear of either side of the buffer-ropes, so as to limit their swing, but at the same time to allow of their hanging freely in the shaft. With the same object in view, a loose-fitting gland around each guide-rope was bolted to the outer beams.

It may not be superfluous to remark that such ropes should not be coiled on reels or drums of small diameter, otherwise they will assume a "set" and hang wavily in the shaft. It may also be mentioned that the plumbed marks on the crowns previously referred to served for the adjustment of the winding-rope pulleys and the detaching-hook catch-plates.

FIG. 22.

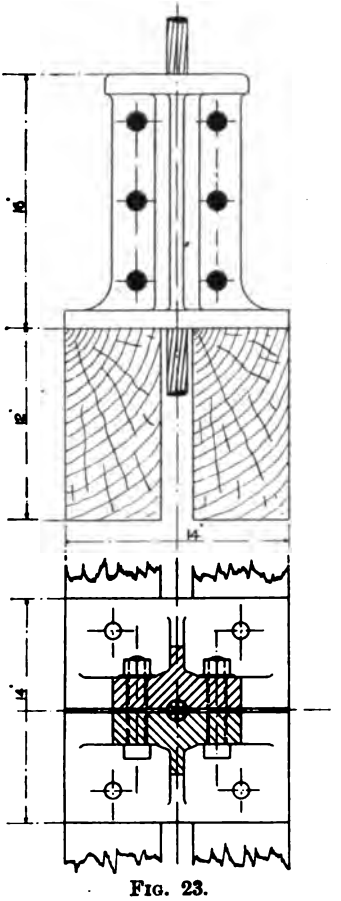


FIG. 23.

FIG. 25.

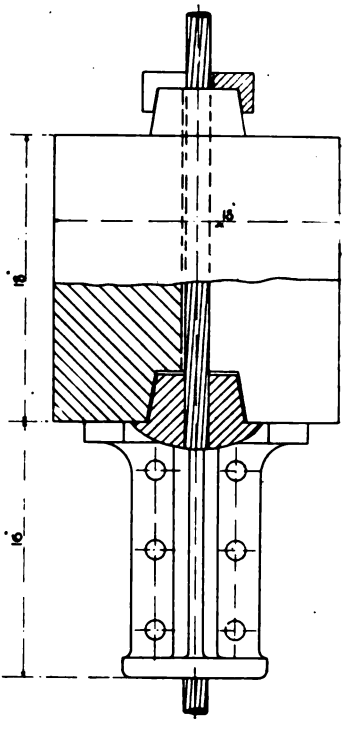


FIG. 24.

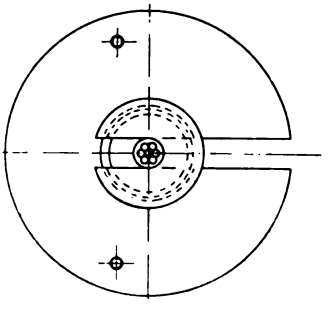
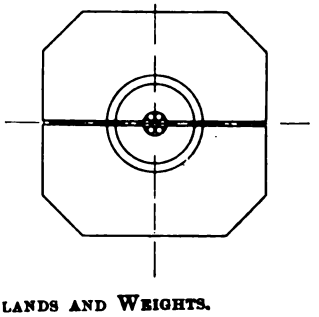


FIG. 26.



FIGS. 22 TO 26.—DETAILS OF GLANDS AND WEIGHTS.
SCALE, 1 FOOT TO 1 INCH.

*Winding Cages.*—In the design of these, an attempt has been made to obtain a strong light structure, easily repaired when damaged, and to conform to the requirements of the Coal

FIG. 27.—SIDE ELEVATION OF WINDING CAGE.

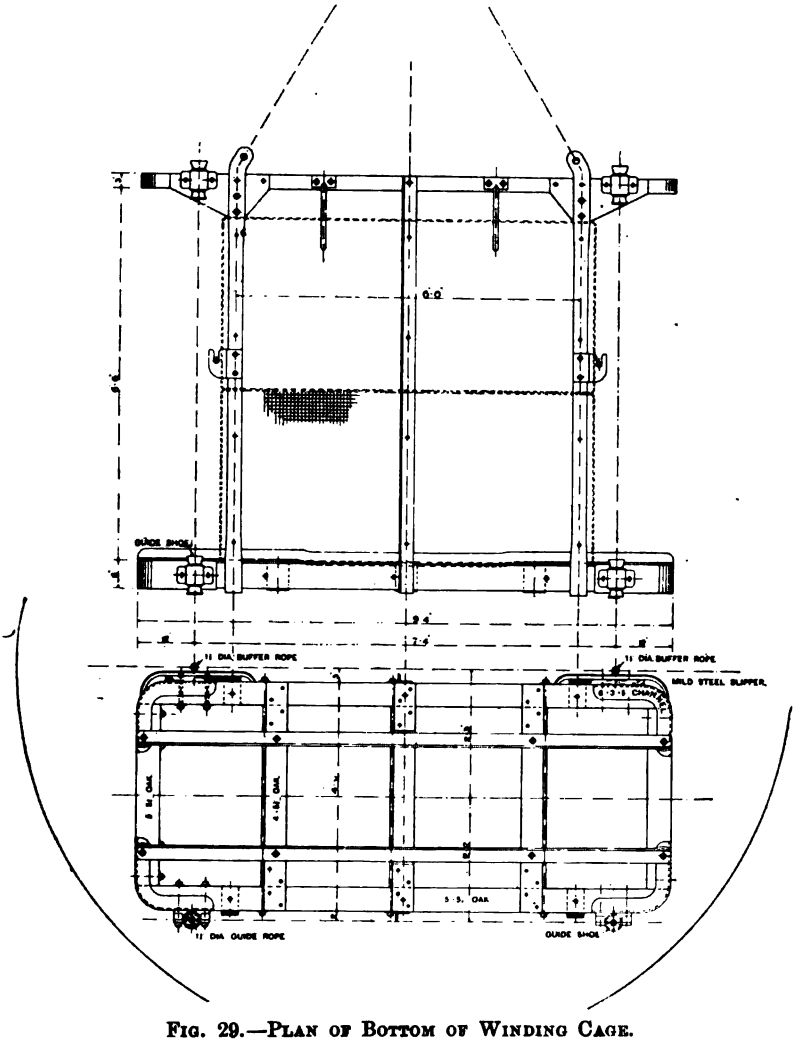



FIG. 29.—PLAN OF BOTTOM OF WINDING CAGE.

Mines Act. The cage is 9 feet 4 inches long, 4 feet wide, and 7 feet 3 inches high, and is suspended by four $\frac{5}{8}$-inch best tested short-link chains, each 5 feet 9 inches long. The bottom frame is made of oak, the sides and ends thereof being 5 inches broad

and 5¼ inches deep. Into the sides of the frame, and securely fastened thereto by ⅜-inch steel plates, top and bottom, are morticed slots, 4 inches broad and 5¼ inches deep. Each of the four corners of the frame is rounded to a radius of 6 inches, and bound with 6 by 6 by ⅜-inch channel-iron. The frame is further strengthened by a binding bolt ¾ inch in diameter alongside each slot. The bottom is clad with deals 1½ inches thick, and the 3 by 2½ by ½-inch angle-iron rails are suitably cressed to form a depression into which the inside pair of wheels of

FIG. 28.—END ELEVATION OF WINDING CAGE.

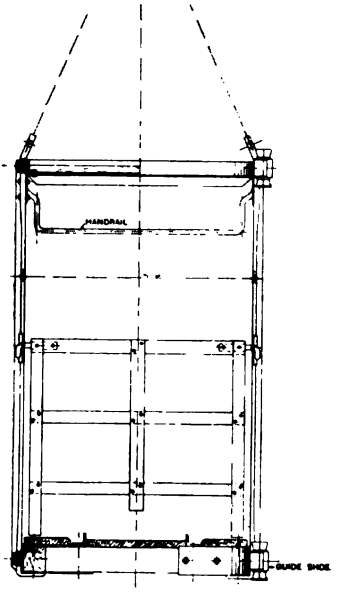
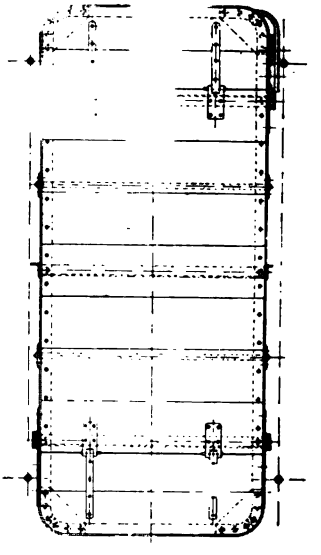



FIG. 30.—PLAN OF TOP OF WINDING CAGE.



FIGS. 27 TO 30.—DETAILS OF WINDING CAGE. SCALE, 3⅛ FEET TO 1 INCH.

each hutch drop, and thereby hold the latter in position on the cage. The legs of the cage are made of 3 by ¾-inch forged iron, swelled out at the top and the bottom to 3½ inches by 1 inch, and on the feet of these the bottom rests.

The roof of the cage is flat, and is carried on bolts ¾ inch in diameter through $\frac{5}{16}$-inch steel gusset-plates riveted to the legs. It is clad over with 11 by 1½-inch white-pine deals resting on a frame made from 3 by 2½ by ⅜-inch angle-iron, jointed at the four corners, and riveted to 10 by 10 by $\frac{5}{16}$-inch steel gusset-plates. In the centre of this frame, and between

each pair of legs, $2\frac{1}{4}$ by $2\frac{1}{4}$ by $\frac{5}{16}$-inch angle-iron tie-bars are fixed. Hinged doors are provided at both ends in order to accommodate long timber and other material which may be carried on the cage. All the angles, channels, and plates are cut, bent (where required), and bored to template.

The sides of the cage are clad with galvanized steel-wire screens, of $\frac{5}{8}$-inch square mesh, made of No. 10 wire on frames

FIG. 31.

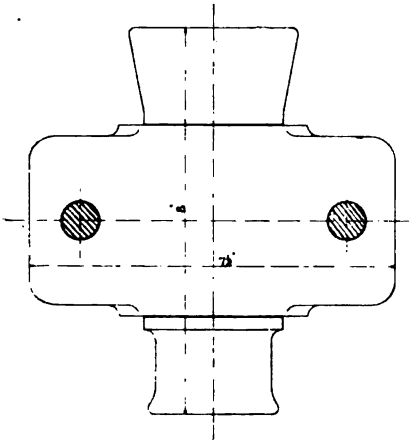
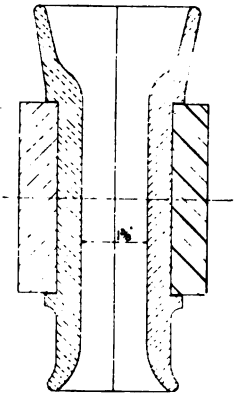


FIG. 32.



FIGS. 31, 32, 33.—DETAILS OF GUIDE-ROPE SHOE. SCALE, 4 INCHES TO 1 INCH.

$\frac{5}{16}$ inch in diameter. These are fastened to the legs of the cage and to central stiffening angle-irons by bolts $\frac{1}{2}$ inch in diameter.

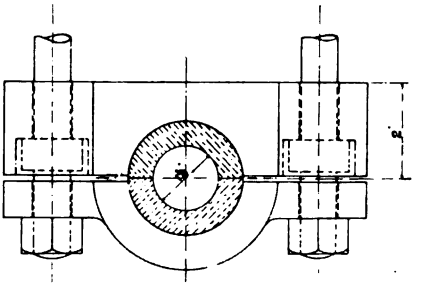


FIG. 33.

Detachable gates are provided. These are made of 3 by $\frac{7}{8}$-inch and $2\frac{1}{2}$ by $\frac{7}{8}$-inch white-pine spars, and are hung on brackets riveted to the cage legs. When being fixed in position, the legs of the gate are placed inside keepers fastened to the bottom of the cage.

One side of each cage is fitted with four guide-shoes, two each at the top and the bottom respectively, placed centre to centre, 7 feet 4 inches apart. They consist of a cast-iron pillow, between which and its wrought-iron cover a brass bush is held rigidly in a vertical position. The bush is made in two

halves, is 8 inches long, ½-inch thick, and is bored to a diameter of 1⅜ inches. The bottom is bell-mouthed and the top cupped to contain grease. The top guides are carried on the side gusset-plates previously mentioned, and bolted through them and the angles of the roof-frame.

On the other side of the cage, and opposite each guide, buffer-blocks are fitted. These consist of mild-steel slippers 2 feet long, 2½ inches broad, and 1⅛ inches thick, rounded on the outside, and curved in against the frame of the cage at either end. They are bolted to the latter with countersunk bolts through oak packing-pieces 1 inch thick, and, so placed,

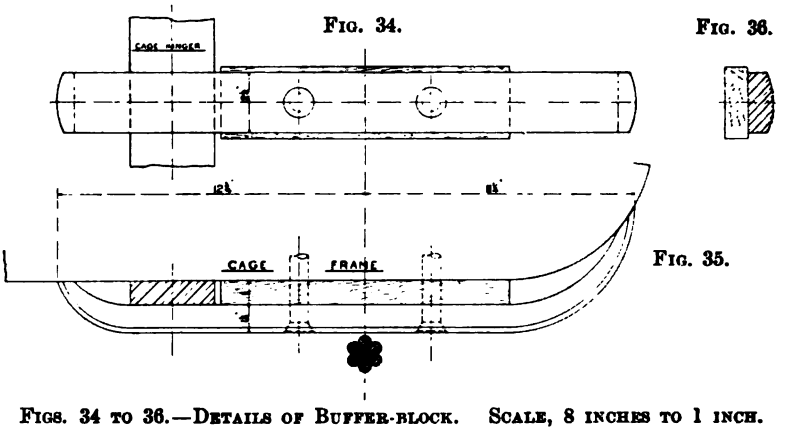



FIG. 34. FIG. 36. FIG. 35.

FIGS. 34 TO 36.—DETAILS OF BUFFER-BLOCK. SCALE, 8 INCHES TO 1 INCH.

are an eighth of an inch clear of the buffer-ropes when the cage is hanging in the shaft.

Figs. 27 to 36 show details of the cage and its fittings, which, complete with chains, weighs 22 cwts.

The clearance between the cages is 6 inches, when these are in running position in the shaft. The writer is aware that the commoner practice is to give greater clearance, and also to provide four guide-ropes to each cage. In such cases the buffer-ropes are closer together than they would otherwise be placed. He, however, fails to see that such an arrangement is essential in order to secure safe and satisfactory travel of the cages in the shaft. What, in his opinion, has to be guarded against is a twist, rather than a swing, of the cages when running. He, therefore, argues that the wider the guide-ropes and the buffer-ropes respectively are apart, the less tendency

there will be for the cage to twist out into the shaft. There is, however, a limit to the distance that the buffer-ropes can safely be put apart. If placed too near to the end of the cage, there would always be the possibility of a longitudinal swing of the cage, allowing the buffer-rope to get round the end of it, and thereby out of action. The curved slippers fitted on the cage are designed to facilitate, in such a contingency, the return of the rope to its correct position more readily than if a square corner had to be negotiated.

*Winding-ropes.*—The winding-ropes are 3⅜ inches in circonference, are of special patent improved steel wire, and the capping is of the tapered barrel type. A 3-ton detaching-hook of the King type is connected to the capping of each rope by a special link.

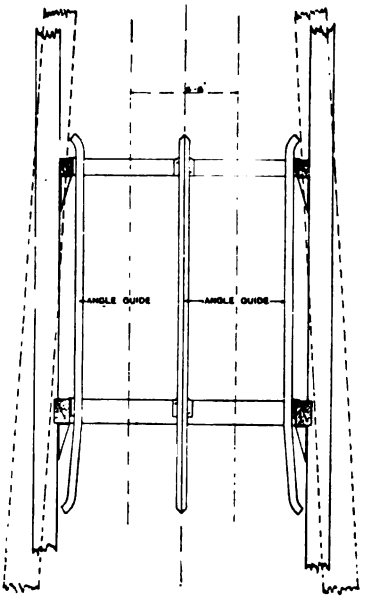


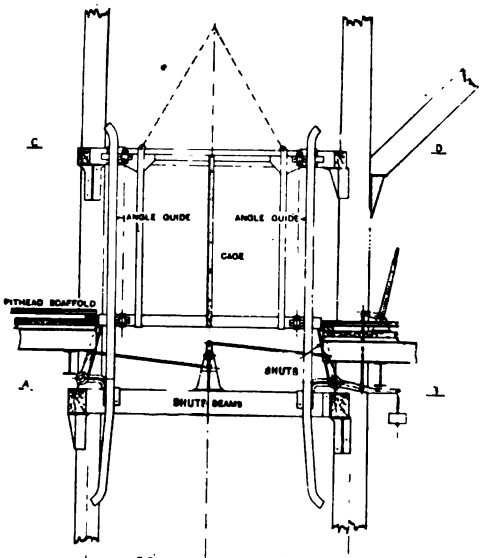

FIG. 37.

*Fixed Cage-guides.*—In order to steady the cage for decking purposes at the pithead level, fixed guides are provided. These are made from 4 by 4 by ½-inch angle-iron, bolted in a vertical position to cast-iron brackets, which are fixed to crowns above the scaffold level, and to others at the level of the shuts beams below (Figs. 37 to 40). The angles are 15 feet 9 inches long overall. The top 6 inches and the bottom 9 inches of each angle is curved back, on the angle edge, to a radius of 12 inches, and a further length of 3 feet of the lower end is set back (also on the angle edge) 3 inches out of line, in order to ensure a safe entrance for the ascending cage.

Each cage is guided on the outside by two such angles, placed an eighth of an inch clear of the guide-rope shoes, while two central angles, looking corner-wise into the shaft, engage the buffer-rope slippers of either cage. An eighth of an inch clearance is provided between the cages and each angle-guide.

*Shuts.*—Cast-iron shuts are installed (Figs. 38 and 39). These are operated by the banksman, assisted by a balance-weight. When not in action, the operating lever is pinned back; but on the pin being withdrawn, the shuts fall out into a position suitable for the cage to rest thereon.

FIG. 38.—FRONT ELEVATION.




The cage is supported on two paw-catches at either end. These are 21 inches long and 5 inches broad, and are keyed to a shaft 3 inches in diameter at a distance of 2 feet 8 inches, centres apart. The catches, when in position for the cage to rest, are steadied by bent

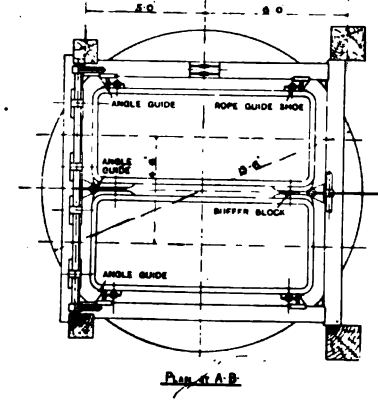



FIG. 39.—PLAN ON LINE *A-B* OF FIG. 38.

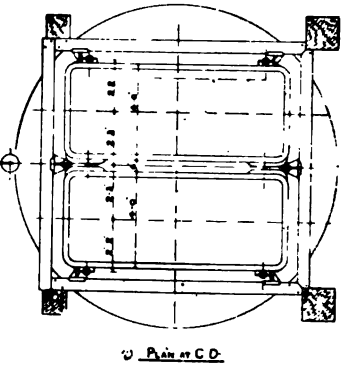


FIG. 40.—PLAN ON LINE *C-D* OF FIG. 38.

FIGS. 37 TO 40.—ARRANGEMENT OF SHUTS AND FIXED ANGLE CAGE-GUIDES AT PITHEAD SCAFFOLD LEVEL. SCALE, 8 FEET TO 1 INCH.

cast-iron arms, which are keyed to the ends of the shafts, and rest on side beams.

*Fencing of Shaft.*—The shaft is surrounded at the surface level by a paling fence about 6 feet high, of which detachable

gates, hanging in keepers, form part. At the pithead level, light timber gates, sliding on angle-iron guides, and operated by the cages, are provided. They are 3½ feet wide and 3 feet 6½ inches high, and are made of white-pine spars 2½ inches broad and ⅞ inch thick, bolted together as shown.

Pieces of 2 by ⅜-inch iron strap, suitably shaped to engage vertical angle-guides fixed between the pithead level and crowns above, are bolted to the extended top and bottom rails.

Pieces of 1½ by 1½ by ¼-inch angle-iron, bent at right-angles, are bolted to the bottom of the standards so as to form projecting feet whereby the gate is lifted by the ascending cage. Hoop-bound buffer-blocks are fixed on the outer sides of the standards, and on these the lowered gate descends and rests in position on the scaffold.

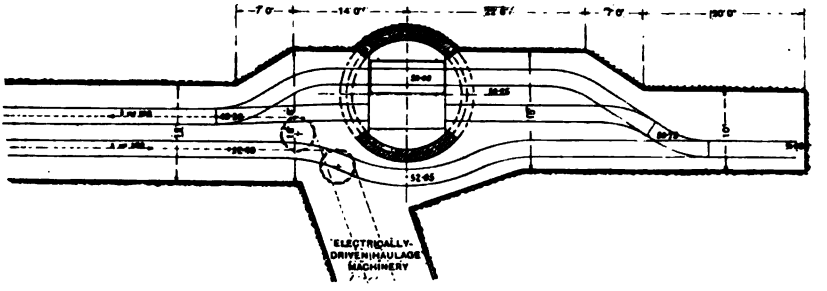



FIG. 41.—PLAN OF PIT-BOTTOM. SCALE, 24 FEET TO 1 INCH.

*Winding-pit Bottom.*—Reference has been made in passing to the forming of the winding-pit bottom. It is 9 feet high up to a good rock roof, and, on the hanging-on side, is about 15 feet wide in the proximity of the shaft. The width, however, is reduced to 10 feet so soon as the convergence of the approaching hutch-roads will permit. On the opposite side it is 16½ feet wide close to the shaft, but is rapidly reduced to 12 feet in width in-bye. Electrically-driven endless-rope haulage machinery is situated close to the pit-bottom, in a place communicating with the old pit (Fig. 41).

The loaded hutches are brought out in rakes attached to the ¾-inch diameter haulage-rope by Smallman clips. These are brought up an inclination of 1 in 10 and over a summit, and detached from the rope on a falling gradient of 1 in 100. The uncoupled hutches, sent off in pairs, gravitate on an in-

clination of 1 in 50 past the side of the shaft, and backshunt into position for being loaded on to the cage. The empty hutches, on being discharged from the cage, run for some distance therefrom, and come to rest on a falling gradient of 1 in 100, where they are coupled into rakes, attached to the rope, and sent in-bye.

*Fencing of Pit-bottom.*—The bottom is fenced on the hanging-on side by wooden gates sliding in channels fixed to the sides of the entrances to the shaft. To each gate a chain is attached, which passes over a vertically-overhead pulley, and then along the roof, and down over another pulley convenient to the pit-bottomer when about to load the cage. A balance-weight, hung from the end of the chain, makes it easy for the man to raise the gate, which, after the cage is loaded, is again drawn down. Fixed bars, placed just high enough to clear the empty hutch, fence the opposite side.

*Conclusion.*—The absence of water in any considerable quantity, and of bad ground to any appreciable extent, made the sinking described a simple matter, when compared with many that have been undertaken elsewhere and successfully carried out. The writer, however, ventures to hope that his description of it will be of some use to the members of the Institute.

# THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

## GENERAL MEETING,

HELD IN THE WOOD MEMORIAL HALL, NEWCASTLE-UPON-TYNE,
APRIL 8TH, 1916.

MR T. Y. GREENER, PRESIDENT, IN THE CHAIR.

The SECRETARY read the minutes of the last General Meeting, and reported the proceedings of the Council at their meetings on March 25th and that day.

The following gentlemen were elected, having been previously nominated:—

MEMBERS—

Mr. ERNEST EDWARD NOBLE, Mechanical Engineer, 30, Ashleigh Grove, Fulwell, Sunderland.

Mr. WILLIAM FENWICK REED, Mechanical Engineer, 16, Princes Gardens, Monkseaton, Whitley Bay, Northumberland.

Mr. DAVID WILSON ROBERTSON, Colliery Manager, c/o Messrs. A. Goninan & Company, Limited, Wickham, Newcastle, New South Wales, Australia.

Mr. JOHN JAMES TURNBULL, Jun., Junior Inspector of Mines in India, Asansol, E.I.R., Burdwan, Bengal, India.

ASSOCIATE MEMBER—

Mr. JOHN HARRY RAMSEY, 17, Victoria Road, Darlington.

ASSOCIATES—

Mr. GEORGE DONALD GOULD, Overman, c/o Mrs. John Gould, 58, Ebers Road, Nottingham.

Mr. HENRY CHARLES HUBERT HANLON, Underground Surveyor, 7, Mark Lane, Whitehaven.

Mr. WILLIAM OLIVER, Overman, 4, Quality Row, Harton Colliery, South Shields.

## DISCUSSION OF MR. SAMUEL DEAN'S PAPER ON "MODERN AMERICAN COAL-MINING METHODS, WITH SOME COMPARISONS."*

Mr. Samuel Dean (Delagua, Colorado, U.S.A.) wrote that, after reading Mr. Hare's remarks, he was inclined to believe that men who were successfully employing bord-and-pillar or shortwall machines in mines with difficult pitches and bad roofs would not place the blame for the failure mentioned at Mr. Hare's mine upon the American operator, but upon the shoulders of the mine manager. As Mr. Hare's remarks appeared to evince a lack of knowledge of machine-mining, and a bitter feeling towards American machine-runners, it would be interesting to have a frank statement from this particular operator as to the reasons for the failure.

Mr. Hare had stated that English longwall machines were as good as American machines, and upon this statement the writer did not intend to comment. He held no brief for any particular machine, but what many people considered the best shortwall machine in America was not advertised in Great Britain, and possibly the machine had never been used in any mine in that country.

When Mr. Hare asserted that in bord-and-pillar working it was *absolutely necessary* to use naked wires in order to move the machines quickly from place to place, he (Mr. Dean) was compelled to say that Mr. Hare apparently did not fully understand the problem. All the wires could be insulated: the power which enabled the machine to travel from place to place was received through the trailing-cable, and the cable was automatically wound up on the reel, or let out, as the machine went backwards or forwards.

The use of 70-pound rails at or near the face was quite unnecessary; 20-pound rails were heavy enough for a shortwall machine when the speed at which it travelled was taken into consideration; and 70-pound rails were for use on main haulage-roads along which heavy locomotives and long trains of cars travelled at top speed.

If Mr. Hare had given a plan of the district of his mine where the American machine was a failure, showing the width of all

* *Trans. Inst. M. E.*, 1915, vol. l., pages 179 and 388; and 1916, vol. li., page 35.

the places—say, every 30 feet—the position of the props and other roof supports, the position and gauge of the track, the section and pitch of the seam, and other data, one might then have been able to adduce some reasons for the failure. If both the bords and walls were narrow, and the mine worked three shifts a day, the machineman would be frequently "held up" by the ponies, or hand-putters, and little tubs, as the roadways would then be congested with traffic.

Mr. Hare thought that no comparison could be made between the working conditions in the two countries, and he (Mr. Dean) would add that this statement was perfectly true where 10-cwt. tubs were used in British mines. No matter what results were obtained with machines, the output per man would never approach the American figure so long as 10-cwt. tubs were employed.

It would be of some interest to learn what was the capacity of the tubs in use in the workings of the new 20-foot seam near Coventry, and what the output per man was expected to be. These frequent remarks about more difficult conditions in Great Britain were not always justified. In the case of Bentley Colliery, it was seldom necessary for a man 6 feet high to stoop when walking from the shaft to the coal-face; the pitch was "just right" to facilitate haulage; the roof permitted of double tracks in the gateways; the seam was 5 feet 4 inches to 6 feet thick, and was perhaps the easiest seam to work that the writer ever saw, as the coal fell over in large slabs when the miner inserted a long iron bar behind the facings. The output per man at the face was about 5 tons, and 14-cwt. tubs were used. The output per man in a similar seam in America would be 10 tons, and about half the number of men would be employed to move the coal from the face to the shaft-bottom. The gauge of the track at Bentley was 26 inches, the rails weighed 28 pounds on main roads and 18 pounds at the face, and props at the face were set 5 feet apart.

To enable Mr. Hare to realize the situation, he might take, say, the Hutton Seam in the County of Durham, where it was approximately 6 feet thick and easy to hew by the scalloping process, and compare the output per man for all men employed in the workings of that seam with the output per man in American seams 6 feet thick. The figures would probably

startle him, and he would not be able to console himself with the statement that the English conditions were unfavourable.

To return to the machine proposition: it was futile to expect an immediate success by placing all the responsibility upon the machine-runner, and that man a stranger in a land of old customs and prejudices. Did Mr. Hare's officials assist the operator? Were they able to assist? Or did they sit at the "kist" and say: "Now, let's see what the Yankee can do?" If they did that, or anything like it, his failure was already assured.

The cause of success or non-success with machines rested with the manager of the mine. The manner in which he planned the lay-out of his workings, his organization, and the way in which he watched daily operations were the factors that governed the results. When a new American coal-cutting machine arrived at a colliery, the mechanics should immediately take it to pieces and build it up again, and should thoroughly satisfy themselves that they understood its mechanism. In the evenings the manager, under-manager, and overmen should attend at the workshops, a mechanic should put the machine into operation there, and afterwards take it to pieces, and the different underground officials should build it up again. This work should be continued every evening until each man understood how the machine worked, and how to remedy defects in it. That was the way in which German mine officials were taught their business at Bochum. When the writer visited the C.E.A.G. electric lamp-works at Dortmund, he saw all the American cap-lamps lying on a table dissected, and efforts being made to improve upon them. The object then was to produce a German electric cap-lamp to be placed upon the American market.

When the official understood the mechanism of the machine, he took a deeper interest in its operation at the coal-face. If the machine "would not work," he ought, after an examination, to be able to state the reason why. If he could not, of what value was he in a mine where the coal was undercut by machines? When a machine was first introduced, the welfare of the machine and operator should be the first consideration. In the event of a breakdown, mechanics should be sent to the coal-face without delay to effect the necessary repairs, or to bring the machine to the shop.

As a rule, machine-runners knew little or nothing with regard to laying out the workings of a mine so as to facilitate machine operation, and this was where the mining engineer should come in. American shortwall machines might be more successful in a mine laid out on the South Wales single-stall method than on the Durham bord-and-pillar method.

Mr. Hare had stated that the illustrations to his (Mr. Dean's) paper showed "vast spaces," with hardly a stick of timber, and immediately seized that peg on which to hang another excuse. It so happened that some of these photographs were taken in

FIG. 1.—AN ENTRY IN AN AMERICAN MINE, SHOWING THE ENTRANCE TO A ROOM AT THE LEFT.

mines where the roof was good, and he would admit that a large number of mines in America possessed good roofs. But, in order to show that machines and large cars were used in mines with bad roofs, he (Mr. Dean) immediately after reading Mr. Hare's remarks had some photographs taken in a mine with a bad roof, situated within a mile or two of his residence (Figs. 1, 2, and 3).

Mr. Hare had said that it was *practically impossible* to use the American bord-and-pillar machines in an ordinary English pit, and he (Mr. Dean) did not propose to allow that statement

to go unchallenged, or to fail to deny it. Surely, the English Government Regulations did not prevent the use of electricity altogether? The United States Bureau of Mines had already placed certain electric shortwall machines on the permissible list for use in gaseous mines, and the Bureau would never have done this if naked wires were necessary.

With regard to timbering close up to the face, Mr. Hare must have seen props set 6 feet off the face and the intervening roof supported by collars resting on props at one end and "needled" into the coal-head at the other. A passage-way 6 feet wide was ample for the latest shortwall machines.

FIG. 2.—AN ELECTRIC SHORTWALL MACHINE TRAVELLING IN-BYE IN A ROOM.

Fig. 1 showed an entry in a mine where the coal was 5 feet thick; on the left the track was shown leading into a room-neck; the duplex trailing-cable of a shortwall machine would be seen on the floor on the left-hand side, and the car seen in the entry had a carrying capacity of 2 tons.

Fig. 2 showed the shortwall machine travelling in-bye in the room. The reel and the insulated trailing-cable were plainly in view, and it would be seen that there were no naked wires, and that the roof had to be supported. The loose props on the left were for the use of fillers at the face.

Fig. 3 showed the shortwall machine cutting across the face of a "crosscut" off the room. A crosscut was a place driven through the pillar to connect between rooms, and in the County of Durham would be called a "wall." In the same county a room would be called a "bord." This particular crosscut was 12 feet wide, and the rooms were 20 feet wide.

One foot of draw-slate generally came down with the coal, and the roof above was full of slips and pot-holes. The maximum distance allowed between props under cap-pieces was 5 feet.

FIG. 3.—A SHORTWALL MACHINE CUTTING ACROSS THE FACE OF A CROSSCUT, OR NARROW PLACE.

The roof over the track had to be supported with cross-bars and lagging.

No special arrangements were made when the photographs for Figs. 1, 2, and 3 were taken. He (Mr. Dean) entered the mine with the photographer, and the pictures were taken just where the machine happened to be. There were many places in the mine far more closely timbered than those shown. This particular machine cut to a depth of 7 feet, and averaged about 100 lineal feet of face per day. It gave so little trouble that the management hardly knew that there was a machine in the mine. It had been in use 18 months, and previous to that time the

opinion was that the roof was not suitable for machines. When it was introduced, the "old timers" predicted failure. It was quite possible that 75 per cent. of the coal produced from this mine would eventually be cut by machines.

He would not close his remarks without congratulating Mr. Simon Tate upon the excellence of his criticism of the paper. If Mr. Tate's statements failed to convince the majority that drastic changes were necessary, then one could not look hopefully to the future. It was unfortunate that what Mr. Tate had written had not received greater publicity. He (Mr. Dean) did not agree with his statement respecting the size of tubs in new pits. If he (Mr. Dean) were to start a new mine, he would aim at having tubs of a capacity of 35 cwt. or 2 tons, instead of 15 cwt. or 1 ton. When once the workman learned how to re-rail quickly a 2-ton car, it gave him very little trouble, and brakes enabled a man to handle the car on varying gradients without difficulty. It was more than a question of getting a hewer's work out: to keep him supplied with an unlimited number of 10-cwt. tubs involved the services of an excessive number of haulage hands; and in a large mine, where all the coal was undercut by machines it would be, to use Mr. Hare's words, "practically impossible" to supply the filler with an unlimited number of 10-cwt tubs. When face-conveyors were used, 10-cwt. tubs were out of the question.

Mr. Samuel Hare (Bishop Auckland) said that he was surprised to read the following in Mr. Dean's reply to his (Mr. Hare's) remarks:

"He was inclined to believe that men who were successfully employing bord-and-pillar or shortwall machines in mines with difficult pitches and bad roofs would not place the blame for the failure mentioned at Mr. Hare's mine upon the American operator."

He (Mr. Hare) thought that everyone who had read his remarks would agree that he had no intention of placing the blame on the operator, but that he quoted the case in question in order to prove that the conditions of English mining were so different from those prevailing in America that one of the best American operators was unable to obtain satisfactory results when using one of the latest types of American heading machines. Mr. Dean then stated that "what many people considered the best shortwall machine in America was not advertised in Great Britain,

and possibly the machine had never been used in any mine in that country," in reply to which he (Mr. Hare) would mention that the machine used was made by what he was informed was the largest company in America engaged in this work, and he could not speak too highly of it. He would also mention that he had several longwall machines in use made by the same firm, and the results obtained from them were most satisfactory.

Mr. Dean also referred to a statement which he (Mr. Hare) had made, that in bord-and-pillar working it was *absolutely necessary* to use naked wires in order to move the machines quickly from place to place, and had concluded his sentence by stating that "Mr. Hare apparently did not fully understand the problem." If this were correct, then he could only say that apparently one, at least, of the best American operators was equally ignorant, seeing that he had given it as one of the principal reasons for his want of success that he was not provided with naked wires for the purpose of "flitting" his machine. Mr. Dean had then explained how it could be done by means of an insulated cable, a method which every novice in mining fully understood, but Mr. Dean did not say that the flitting by this method could be carried out *quickly*.

Although (speaking from memory) Mr. Dean had not given much information in the paper as to whether naked wires or insulated cable were used in connexion with the machine described by him, he (Mr. Hare) had arrived at the conclusion (assisted by the illustrations) that bare wires were being used. If, however, Mr. Dean, with a better knowledge of American mining methods than he (the speaker) could claim to possess, stated that heading machines could be flitted quite satisfactorily by insulated cable, then he was bound to accept that statement, and must come to the conclusion that the different conditions at the face were entirely responsible for the failure of this particular machine.

Mr. Dean had called attention to the Hutton Seam in the County of Durham. As at one time he (Mr. Hare) had been manager of the largest pit in the county working the Hutton Seam extensively, it might interest Mr. Dean to know that at this particular colliery, and at most of the others with which he was acquainted where the Hutton Seam was being worked, neither naked nor insulated wires of any description would be

tolerated in any part of the mine. How then could any comparison be made between the output per man from the Hutton Seam —lying very often at great depths, with great roof pressures, and also with firedamp present in large quantities—and machine-mining in comparatively shallow mines of good section, where electricity could be used with impunity?

He thought that he might fairly dismiss without comment Mr. Dean's suggestion that the operator might not have received sufficient assistance from the officials. Needless to say, every suggestion made by the operator was most promptly and willingly acted upon.

Mr. Dean had referred to his (Mr. Hare's) allusion to the "vast spaces" containing hardly a stick of timber, but Mr. Dean himself was surely responsible for any one arriving at that conclusion. A glance at Figs. 27 to 32, 36, 38, and 40 to 46, would demonstrate that the conditions shown in these illustrations could not possibly be found in any English colliery.

Mr. Dean had now presented three additional illustrations, in an attempt to prove that there was not much difference between the face conditions prevailing in England and in America. It was not necessary, however, to examine these new illustrations very closely to find that Figs. 1 and 2 were not views of face workings such as those shown in the paper, but were evidently roadways, which one might naturally expect to be timbered.

As to Fig. 3, it was the only illustration out of seventeen that showed any timber at all at the working-face, and he thought that it might be fairly assumed from this that in this particular place there was some abnormality present—possibly a fault or hitch which had affected the roof.

In comparing American and English mining practices, there were several other points that Mr. Dean ought to have taken into consideration before making such sweeping allegations—for instance, the gradients met with in both countries. He (Mr. Hare) had always understood (and here again the illustrations would bear him out) that the American Coal-Measures were almost horizontal, whereas in Great Britain in several of the coalfields they were highly inclined. In some of the pits under his charge the gradients varied from 12 to 24 inches per yard, and under these conditions machine-mining with bad roofs became almost an impossibility.

In conclusion, he could only repeat what he had already stated in connexion with American mining practice- he recognized and admired the skill shown by American mining engineers in the design and application of machinery to mining, but, at the same time, he claimed that Mr. Dean had failed absolutely to prove that it was possible to obtain anything like the same results in Great Britain, even by applying the best mining machines, and to the same extent, as in America.

The PRESIDENT (Mr. T. Y. Greener) said that it must be obvious to everybody who had considered the matter that the chief reason why the output per man in the American coalfields was so much larger than that in England was not due to want of skill on the part of English mining engineers, but to the different conditions prevailing in the two countries. America was now in very much the same position as Britain was 40 or 50 years ago. The Americans were now working their best and thickest seams, and, apart from that, they had all the advantages of the appliances that had been discovered during the last 30 years; they had also the advantages arising from the use of electricity and other power; and these were sufficient to account for the difference in the output of the two countries.

He gathered that there was a very general idea in America that the use of large tubs was the solution of the difficulties with which they in England had to contend. He wondered what Mr. Dean or anyone else would say to the use of large tubs of, say, 2 tons capacity in the thin seams which were being worked in various parts of the country to-day. Those seams varied from 20 to 22 inches in height, and he thought no one would suggest the use of trams containing 2 tons under such conditions. To begin with, the cost of making the roads would be absolutely prohibitive, even assuming that it was only necessary to make roads every 100 yards. The idea that if large tubs were adopted in Great Britain the output would immediately approach that of the United States seemed to him absurd and impracticable.

He did not know why reference had been made by Mr. Dean to Bentley Colliery, because it was perfectly well known that at Bentley nothing in the shape of electrical machinery was admissible underground, owing to the quantity of gas present. He thought that this went to show the impossibility of comparing the results obtained in one country with those obtained in

another, unless it was possible to reproduce the same conditions in each country.

They were very much indebted to Mr. Dean for bringing the paper before them; it was certainly a paper that would spur them on to do whatever they could to approach more nearly to the output of American mines; but there was nothing in Mr. Dean's paper which went to show that English mining engineers were lagging behind, either in the adoption of labour-saving plant or in other scientific appliances.

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## DISCUSSION OF MR. HIRAM H. HIRSCH'S PAPER ON "THE HIRSCH PORTABLE ELECTRIC LAMP."*

Mr. PERCY L. WOOD (Clifton) wrote that, in his opinion, the lamp battery was too small; it might give no trouble for a short period, but he was confident that, with the ordinary knocking about that lamps received in the colliery, it would not give satisfaction for long. His experience of electric lamps was that as new lamps were required the makers, instead of supplying a lighter lamp, recommended an increase in the size of the battery. This, he thought, was the only way to secure a reliable light.

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## DISCUSSION OF MR. JOHN GIBSON'S PAPER ON "THE LOGIC OF TRAMS."†

Mr. ARNOLD LUPTON (London) wrote that doubtless many advantages would result from the standardization of pit-trams, but there were many difficulties in the way. As the conditions of collieries changed every day, it was important that the trams should suit the special circumstances of each pit.

The exterior dimensions of the tram were governed, amongst other circumstances, by the diameter of the shaft, the most economical width of the roads, the height of the working-place and the most economical height of the roads, the gradient, the habits of the miners, the method of haulage, and the most con-

* *Trans. Inst. M. E.*, 1916, vol. li., page 61.

† *Ibid.*, page 72.

venient weight of the loaded and empty tram. It would not be economical to alter the dimensions, as fixed by the foregoing considerations, for the sake of any reduction in first cost of the tram or of repairs.

In mines where the loaded tram moved downhill, the cost of haulage was, to a great extent, measured by the cost of getting the empty tram to the place where it was filled. For that reason it was economical to make a tram as light as possible, in proportion to the weight of coal that it contained. It was also advisable to make the weight of coal contained in a tram as great as possible, having regard to the external dimensions, because upon these external dimensions depended the space occupied by the trams in the mine and in the cage for any given output of coal.

It was frequently the case that the dimensions, shape, material, and form of construction of a tram were designed chiefly to save first cost and the cost of repairs of a given number of trams; whereas it could easily be shown that, where sufficient capital was available, the first cost of a tram and the cost of tram repairs were matters of much less importance (having regard to the total costs of the mine) than the possession of a tram of the best possible design and construction (having regard to the cost of haulage, road repairs, and output). A tram which held 10 per cent. more coal for a given weight and external dimensions would enable the manager to obtain a 10-per-cent. greater output from a pit in which the colliers were able to fill all the trams that were brought to them.

A tram should be so designed, both in regard to construction and lubrication of the wheels and axles, as to work with a minimum amount of friction. It should have spring buffers (which he, Mr. Lupton, had designed and used), and the body of the tram should be carried on springs if it were found possible to design suitable springs without adding unduly to the weight and external dimensions of the tram. Springs reduced the breakage of coal in transit and the damage to the trams in a collision.

An ordinary colliery manager was reluctant to design and order the best possible tram for fear that he would be criticized for the expense in first cost and repairs. These expenses would be obvious, but economies would not; and he would therefore prefer the experiment to be made by someone else.

Mr. W. R. PECK (Big Stone Gap, Virginia, U.S.A.) wrote that it appeared to him that the author had "put the cart before the horse," for, in suggesting the standardization of mine-trams and track, he had placed the tram first, and had given very good reasons for so doing; but, in order to reach this standard, the track-gauge should first of all be considered, and it ought to a greater or less extent govern the size of the tram. The height, width, and length of the tram could be varied and still maintain a close approximation to the standard; but, owing to the modernization of haulage, locomotives, and mining machinery, and to the near approach of the time when steel ties would replace those made of wood, and steel would replace wood in timbering, it seemed conclusive that a track-gauge standard should come first. In considering this point, one must not only think of the coal that would come over the track, but also of every piece of machinery that could be used to advantage in the recovery of the coal. The day had now arrived in the United States when the mining company that neglected its underground transportation lost dividends for its stockholders.

The secret of successful mining was primarily successful transportation; this statement was true in almost all industries: it was easy enough to grow grain, but if it could not be taken to the market cheaply and readily, all the profits would be lost. The coal in the ground cost but little: for a small price it could be dug and loaded on to the tram, and for a certain price the railroad or steamship lines would haul it away; but was it easy to get this coal from the working-face to the railroad-car? The complexities of underground transportation in a mine of the present day were such that they would baffle the ingenuity of many a railway traffic superintendent if he were called upon suddenly to tackle the problem in a mine.

It was necessary, therefore, to establish not only a standard gauge for the track, but one that would and could be satisfactorily used throughout, both underground and at the surface. One could not hope to meet all conditions, but the endeavour, in the selection of the standard track-gauge, should be to approach as near the ideal as possible.

Mr. Gibson had recommended a gauge of 24 inches; but such a gauge was too narrow. This particular gauge had been decided upon for two reasons—the man power, and the width of the

gate-road. Given a car or tram of the same weight, a man could push it as easily on a gauge of 42 inches as on a 24-inch gauge; and if proper pack-walls and cribs were built in longwall mining, and proper timbering were used in the room-and-pillar work, a track-gauge of 42 inches could be maintained as well as one of 24. Perhaps the cost of the pack-walls and the timbering would be greater with the wide than with the narrow gauge; but the saving in transportation and capital invested would more than offset this extra expense. It was true that a tram for the wide gauge would have a greater dead weight than the tram for the narrow gauge, but it had been proved in America that the advantage was with the wider gauge. In the selection of this standard track-gauge and tram, one must not lose sight of the fact that the day of man power, and, to a large extent, horse-power, for haulage was gone. Electric and gasolene power was employed in America, not only on the main haulage-roads, but at the very working-face. This fact demanded larger trams: if the coal-bed was thin, a wide, long, but low tram was used; if thick, not only a wide and long, but high tram was employed. The miner would not have to handle it, as it would be placed for him by mechanical power.

The general idea of Mr. Gibson's paper was good: standardization was the keynote of the times, and this had resulted in large savings being effected in many other industries, as it would in mining if properly applied. A broad standard gauge should be established—not to safeguard the mine-tram as it existed to-day, but for the standard tram of the near future. This standard tram should be such that, even in the thin seams, its capacity would not be less than 1,000 pounds, and his (Mr. Peck's) preference was for one of at least twice that capacity. Trams of a capacity ranging from 2,000 to 2,500 pounds were being used in mines in America in seams from 24 to 30 inches thick. The trams were very low, but long and wide, with small wheels.

The suggestion that mine-rails should be manufactured in multiple units was very good, and, if adopted, would result in the saving of much time and money in the laying and maintenance of the track.

He gathered from Mr. Gibson's paper that it was thought that American mine-operators paid more attention to the track than was the case in Great Britain. This might be on account of the entirely different mining conditions, but very likely it was

due more to the fact that in America a larger tram and more mining machinery were used. For this reason American mining engineers had adhered to the wide-track gauge, and had endeavoured to make their mine-tracks compare favourably with the railway-tracks. Mr. Gibson had spoken of the desirability of small trams, on account of the right-angled turns and short-crossings that were encountered. A great many of the American mines turned their rooms at right-angles, but switches were put in, the same standard switch being used throughout the mine, so that the small gathering motors had no trouble in taking these switches. Man power for haulage had disappeared in America; it was cheaper to use mechanical haulage even at the working-face, and therefore American mines had introduced a wide gauge and a large car or tram, with the result that the miner as well as the operator realized the benefit. American mines had not as yet standardized their tracks or their cars, but such standardization would come in the near future.

His criticism of Mr. Gibson's paper was based entirely on mining conditions as they existed in America, and probably would not fit the present conditions of English mines. One must remember, however, that the standard track and tram ought not be made to suit the mine conditions of yesterday, or even of to-day, but, rather, the mistakes discovered in the past and present should be taken into account, and tracks and trams designed that would be suitable for the mines of the future.

Mr. SAMUEL DEAN (Delagua, Colorado, U.S.A.) wrote that the paper should only be the first of a series dealing with the mine-tram, because it would take considerable time to arrive at anything definite in regard to standardization.

There were no standard mine-cars in America. He had agitated for them for the last 18 months; but the American mining engineer had the consolation of knowing that his cars or trams were generally large enough for his purpose. The British mining engineer, on the other hand, was in a dilemma; he had "cut" his pit according to his car, and, as his car was usually ridiculously small, his output per man was in the same ratio.

Mr. Gibson had stated that at one British colliery a 2-ton tram might be used, while at another, under not dissimilar con-

ditions, a tram to carry only 4 cwts. might be employed. By "stepping up," a similar comparison could be drawn in America. A 30-cwt. car could be seen in one mine, and a 4-ton car in another, yet the thickness and pitch of the seam, and the nature of the roof and floor, would be similar in both mines. The more one considered the mine-tram problem, the more one realized that some mining engineers or "practical mining men" had overlooked something of vital importance in this connexion.

Mr. Gibson had asserted that if coal had to be moved 10 feet, or 10 yards, or 100 yards, the best methods to employ would be shovelling, wheel-barrowing, and tramming respectively; but it all depended upon the quantity of coal to be moved. A large quantity of coal, or of earth on the surface after ploughing, could be moved more quickly and cheaply by "scraping" than by shovelling or wheeling. By "scraping" he (Mr. Dean) meant the use of a scraper, holding about a ton, drawn by a team of mules. As the quantity of material and the distance increased, the use of steam-shovels, locomotives, and side or end-tipping wagons became justified.

He would ask Mr. Gibson to explain why it was necessary to turn gate-roads off crossgates at right-angles? The turn-plate and the flat-sheet were, in his opinion, old-fashioned, and should not be employed in modern mines. When a tram left the rails on one side of a flat-sheet, the man who pushed it was often delayed some little time in his effort to find the rails on the other side, and these short delays mounted up considerably at the end of a day, a week, or a year. These sharp right-angled turns also prevented the use of a long tram. This was an important point, when it was remembered that what was wanted was length and width, not height.

Mr. Gibson had also stated that "in gate-roads it is . . . cheaper to draw by hand to the limit of inclination, rather than resort to self-acting inclines of any kind." This, however, was a matter needing much concentrated thought. Was there no other way of conveying the coal to the levels? Could gateway conveyors not be used, and the drawers sent to do other and more useful work? Mr. Gibson spoke of drawing to a "lye" 500 yards out-bye. This meant (if 10-cwt. trams were used) that a drawer would have to travel a distance of 1,000 yards for half a ton of coal, or 2,000 yards for a ton.

Such an arrangement appeared to be an amazing waste of time and energy, and it was therefore not at all surprising that the national output per man was low.

The general lay-out of the mine workings appeared to be governed by the size of the tram. If a manager in America were about to open a seam 3 feet thick, pitching 10 degrees, he would reason somewhat like this: "I shall have to work the seam in a certain way, because I shall have to use the 2-ton cars sent here from an abandoned mine." His cars would thus govern his method of working underground, and it was a foregone conclusion that the cars would not be pushed between the "lye" and the working-face, whilst his output per man would be higher from this seam than the average production from a seam of the same thickness in any other country.

This brought one to a consideration of the following plain question:—If the seam were 3 feet thick, and it was proposed to use trams of a capacity of 2 tons, how must the workings be laid out in pitches of 3, 6, 9, 12, or 24 degrees to allow of the trams being moved with the minimum amount of physical power and the maximum conservation of time? That was a question which only a man with very wide experience could answer, unless he were given time to find out how seams 3 feet thick on these different pitches were being worked in modern mines in all parts of the country. When it was remembered how difficult it was for one to obtain information (sometimes one was not permitted even to look at the surface arrangements of a colliery), the value of friendly co-operation between different countries would be realized. Many men, who could throw light on this problem, would read the present discussion, but, from a false sense of their duty, or on account of their lethargy, would remain silent. These were the men who received, but seldom gave.

Where main gates dipped to the face, small hoists at the top would handle very satisfactorily single cars of a capacity of 2 tons; and if the "level" gateways dipped slightly to the face, the lad at the end of the rope could easily push the empty to the face by pulling in the light flexible rope that passed round the centre pulley at the switch. When the tram reached the face, it was switched on to a movable side-track and the rope hooked on to the loaded tram, which was then pulled

out. The extra width of gateway was only required for a short distance back from the face. As the switch or crossing was moved forward, the space behind could be gobbed with *débris*. This, of course, meant extra width of brushing, and might be objectionable in some mines. The alternative, then, was to have short gateways and to have the rope to pull the trams and deliver them to the mouth of each gateway, the trams being pushed by hand over the short distance between the dip-road and the face. The amount of time consumed in pushing or drawing was not serious, because with 2-ton cars it was only necessary to travel between the dip-road and the face of each place a few times a day, the track being laid just slightly in favour of the loads on the levels.

In America drawers or putters were not employed, and in 20-foot rooms that were worked double (two men) the driver often left the empty tub at the room-neck and the two men pushed it to the face. On his next journey the driver left his empty at the same place, took his mule to the face, and pulled out the loaded car; or, if the place were driven in favour of the load, and was too low for the mule, one of the miners "dropped" the loaded car down to the switch, riding behind on the bumpers, and gently applied the brakes when required; he also used the brakes to stop the car. Frequently the driver took two empties from the flat or parting, left them at adjoining room-necks, and returned with two loaded cars. If the cars were not too heavy, and he had a strong mule, he could handle three or four cars at a time.

Mr. Gibson had stated that "brakes were inadmissible," but in this instance he had made a serious mistake. In the case of 30-cwt. or 2-ton cars, brakes were indispensable, and no man who had used them would willingly go back to the "mediæval" method of using "sprags" or "lockers."

He (Mr. Dean) would warn anyone who contemplated using large cars not to strive unduly after lightness. Some of the most serviceable cars of 2 tons capacity weighed about a ton, although by using the very best material in the wheels and axles this weight might possibly be reduced a little.

He preferred the term "switch" to "short-crossing," and there was no necessity to use two words when one sufficed. He preferred "frog" to "heart," and "latches" instead of

"wings." At room-necks fast points were generally laid, and the man who pushed the car applied side pressure to turn it to the right or to the left. He was glad to see that Mr. Gibson had adopted the word "track," but for heavy tracks nails were inadmissible, and spikes or dogs must be used. Steel sleepers or "ties" were preferable to those made of wood in low roadways. Such sleepers had already passed the experimental stage, and where heavy coal-cutters were used they tended to hold the track to the proper gauge. He did not think it wise to adopt a standard rail-length of 4 feet for heavy traffic. He disagreed with the suggestion of a track-gauge of 24 inches for trams of 2 tons capacity, and considered that the minimum gauge should be 36 inches.

It would appear that there was room for much improvement in railway equipment. A country that used 10 and 12-ton railway-wagons would feel the effects of world competition later on. In 1900 the Pennsylvania Railway scrapped and burned all wagons of a carrying capacity under 40 tons, regardless of their condition. The Norfolk & Western Railway now used "hopper" wagons of 100 tons capacity.

Mr. Gibson's suggestion that cages, headgears, etc., should be standardized was excellent, provided that matters were so arranged that later improvements could be incorporated in the standard design; but, when he spoke of the Germans being beaten at their own game, he left the impression that some stupendous revolution would be necessary to bring that change about.

In conclusion, he would suggest that mining engineers in South Wales would be merely doing their duty if they described how they handled their large trams under the different working conditions that prevailed in that coalfield.

Mr. Ralph W. Mayer (Roslyn, Washington, U.S.A.) wrote that the better an American mine was managed, the less was the tramming done by manual power. Animal or mechanical haulage was cheaper and quicker, and resulted in a much larger output than would be the case if the cars were moved by manual power to any considerable extent. A large tonnage of coal could thus be produced on a smaller initial investment for mine development and equipment. The workings would be more compact and more easily supervised. The expense of maintaining the roads, timbering, etc., was less for the smaller area

than it would be if a large area were necessary to produce the required tonnage, on account of an inadequate haulage system, such as tramming by man power. The steamers in the Orient were coaled by men and women, who packed the coal aboard the boat in baskets, for which labour they received from 3 to 12 cents a day. In similar circumstances, and with cheap wages, it was barely possible that tramming by man power could compete successfully with well-equipped mechanical haulage. The coal-miners of the United States, particularly those in the west, were comparatively well paid, yet the tonnage cost of the coal produced there compared very favourably with that at mines which were not operated with the latest mechanical equipment. It was unlawful in most of the States to employ underground boys less than 16 years of age, and to put these young boys at tramming cars—work which was beyond their strength—was questionable, both from the economic and the humanitarian standpoint.

In American mines, when the seams had sufficient pitch, the coal was run from the working-face to the entry down shoots, sheet-iron being used when necessary to make the coal slide more easily, and it was then loaded from the shoots into the cars at the entry. In seams where the pitch was insufficient to enable the coal to slide down the shoots, gravity planes were used. As the loaded car descended from the working-face to the entry, it hauled the empty car from the entry up to the working-face. When the roof was sufficiently high, animal haulage was sometimes used in the rooms.

Locomotives which could be operated in very low seams were now manufactured. The gathering locomotives obtained their power from compressed-air storage-batteries, or from a cable hooked over the trolley-wire on the entry, and unreeled from the locomotive as it entered the room. Very few seams were so low that some type of these locomotives could not be profitably worked; and, even if some of the roof had to be taken down for the purpose, this method was considered more economical than tramming by man power.

Turntables were antiquated and out of date in any well-managed mine. They caused the loss of too much time and too much hard unnecessary work. Their use might be excused in driving some prospect in order to determine the value of a seam,

but not in a working mine. Curves and switches were in almost universal use.

Andrew Carnegie did not hesitate to scrap machinery, even if it had never been used, when some other machine which would do the work more cheaply and better was invented, and he made money by doing so. Many mine-operators would do well to follow his example and scrap their old cars, which had worn bearings, and were of an old style, instead of taking them for use at a new colliery. The use of the old cars was economical, in that it saved cars, but probably very extravagant in tonnage cost of haulage, when compared with more modern cars having ball or roller-bearings and all the latest improvements. Car wheels, of large diameter, had a smaller coefficient of friction, and consequently helped to reduce haulage costs. When ball-bearing cars, with modern oiling devices, were used, the additional amount of coal that a locomotive could pull would repay the cost of the cars in a short time, and make the scrapping of the old cars an economy.

Steel rails, the bolt-holes in the rails, bolts, fishplates, etc., were all standardized in America, and a damaged rail could be removed and immediately replaced by another which was an exact duplicate. The different gauges of the cars were to a large extent standardized by the manufacturers also. The car-boxes for the coal-mines were generally made of wood. They were more easily repaired, and less work was entailed in clearing up a wreck than when the boxes were made from any other material. Steel boxes bent, and if they broke a more expensive repair plant was necessary than in the case of wooden boxes, although steel boxes were used largely in metal-mines and also in some coal-mines. Car-brakes were much used in some districts, and if simple in construction and well made would stand very rough usage. Possibly they were not often necessary. Cars having short wheel-bases were much more easily replaced on the track if derailed than those that had long wheel-bases. When the tracks near the working-face were bad, the best plan was to make the track-layers do better work, or else get new track-layers. Steel sleepers were good, but they also required to be carefully laid. It was inconceivable that any well-regulated and managed mine would lay a curve having an awkward twist in it such as that illustrated in Fig. 4 (Plate III.). It was not advis-

able to patch a track with short pieces of rail, but where this was necessary wood should not be used, as it was impossible to make a good track for the haulage of heavy loads with wooden patchwork. Short pieces of steel rails, with ties laid underneath them, and having bolt-holes drilled in each end, should be used. They should be fastened to the longer length of rails by means of fishplates and bolts, in the same manner as any other rail-joint was made.

Mr. James Ashworth (Vancouver, British Columbia) wrote that the paper lost interest because Mr. Gibson had not given detailed plans of any one of the standard sizes of trams advocated. He (Mr. Ashworth) was of opinion that the early introduction of standardized dimensions for either trams or "track" was most unlikely. In the tabulated dimensions given by Mr. Gibson, the largest tram had a depth of only 28 inches and a height over all of 46 inches, whereas it seemed desirable to fix both a maximum and a minimum standard height in order to meet his views with respect to the size of the proposed base.

In Mr. Gibson's note on the circumstances that governed the size of the tram, he did not appear to have devoted sufficient attention to the question of ventilation, the depth of the mine, and the character of the roof and floor; consequently, he erred when stating that the tram governed the size of the road. Mr. Gibson's plea for a one-clause Mines Amending Act was certainly more than a surprise, and most mining engineers would be of opinion that the Secretary of State could occupy his time much more usefully than in considering the question of the standardization of the gauges of rails—a matter which had no material influence on the safety of the mine or on the lives of the miners working therein. It did appear to him that the standardization proposed by Mr. Gibson would not add to "national efficiency" and reduce the cost of production, or that in any economic war which was likely to ensue British mining engineers would not be able to beat the enemy.

Mr. John Gibson (Kilmarnock) wrote that Messrs. Peck's, Dean's, and Mayer's contributions might be fairly summarized in the words of Mr. Price Collier, a well-known American observer, that "England is the land, not of logic, but of com-

promise." This dictum was to some extent borne out by the discussion, for whereas the American critics were keen supporters of standardization, or of anything else likely to reduce cost, those in Britain were cautious and doubtful of supporting any far-reaching departure from usual practice.

Englishmen used small trams; but this was more likely to be due to conservatism than to lack of logical sequence. Americans used large trams; but this indicated a difference from British practice which was not necessarily better or more logical. Further, American practice lacked uniformity, just as in Great Britain. On the one hand, the trams varied from large to very large, and on the other from large to very small. His own contention was that, for every particular set of conditions, a tram of a certain size was most suitable, that by standardization the tram approximately most suitable to a given set of conditions was easily procurable, and that change was easy if an error were made or if the conditions altered.

He was afraid that Messrs. Dean and Mayer had not safeguarded themselves against the fallacy of supposing that a principle true in the abstract must hold good in all sets of circumstances. Mr. Dean, for example, had stated in effect that: (1) not only did large trams suit American conditions (with which he was presumably familiar), but also Indian, Chinese, Australian, and all other conditions. (2) That in extreme cases in Scotland trams were hand-drawn for 500 yards, which as a general practice was indefensible; but Mr. Dean had also asserted that it was wrong in any case, which showed quite clearly that he had not considered an extreme case. (3) Mr. Dean, with justifiable pride, had stated that "a country that used 10 and 12-ton railway-wagons would feel the effects of world competition later on. In 1900 the Pennsylvania Railway scrapped and burned all wagons of a carrying capacity under 40 tons." In a huge country such a course was good business; but would Mr. Dean urge such a policy for Scotland, where the bulk of the coal was burned or shipped not 50 miles from where it was mined? In the same way, would he hold that because a 40,000-ton liner was suitable as an Atlantic ferry it would be suitable as a ferry-boat on the Tyne, Clyde, or Mersey? It would be unkind to press further this aspect of American criticism.

Mining engineers in Great Britain had much to learn from

their American friends, and possibly the best way to obtain help was for the former to lay before the latter the chief features of their particular difficulties. The extreme case for the small tram would, then, of course, be brought into relief, as under:—

(1) Great Britain was a very old mining country, and one result of this was that nearly all the easily-won seams were exhausted. Let them take as an example an old colliery with six seams, and see how the preceding generations had worked them. The collieries being financial, and not philanthropic concerns, the seam or seams most in demand and cheapest to work were first attacked. The present-day conditions might be as follows:— No. 1 (the top) seam was of poor quality, and the roof was much racked through the working of the lower seams. The good seams (Nos. 2, 3, 4, and 5) were exhausted, except for small areas in troubled ground, to be won through cross-cut mines. No. 6 was a thin seam liable to inundations from waste ground overhead. Blackdamp or firedamp and water were plentiful. In one case within his knowledge a preceding generation had extracted 70 per cent. of a 5-foot seam, and had then abandoned it. The present working was like an uncharted archipelago of small islands of coal surrounded by seas of dirt. Even the dross and dust left behind by the old miners was carefully extracted, washed, and put on the market.

As a general proposition, it would be admitted that to make a colliery of this kind pay required not only push and go, but thrift, carefulness, and caution. Any wild-cat scheme of development or equipment would surely end in bankruptcy.

With regard to Mr. Mayer's sweeping dictum that "turntables were antiquated and out of date in any well-managed mine," he (Mr. Gibson) might mention a case well known to him of a seam 2 feet thick opened up by the longwall method of working. A level was driven a distance of 160 yards in 22 weeks, the rise given being 1 in 60. Careful levels were taken from time to time, and it was found at the end of six months that the floor from the starting-point to a point 60 yards from the face was 4 feet above the original level, although 3 feet had been taken off; in other words, the pavement "creep" was 7 feet. There was enormous pressure on the sides, which were very frequently retimbered, and although the road had a general gradient of 1 in 60, pools of water 6 inches deep formed on it. Turnplates for

obvious reasons were used, and had to be relaid entirely every month. Strenuous efforts were made to maintain the road 3 feet wide by 3 feet in height. Of what use would large trams with roller-bearings, locomotives, and well-laid crossings be on such a road?

In an old mining country local customs, practices, and prejudices grew up, and even the best laid schemes which interfered or upset these had to be very carefully introduced and handled. For instance, any proposal which rendered unnecessary the use of lads under 16 years of age underground would have to provide other equally remunerative employment for these lads, or fierce resentment and opposition to the scheme would surely result.

(2) Great Britain was not only an old mining country, but it had a single Mines Act, which applied to the whole country, with all its varied conditions. Americans could imagine for themselves what results would follow if the whole of the mines from the Atlantic to the Pacific were subject to the same regulations. For example, a firedamp explosion in Pennsylvania might cause the prohibition of electric locomotives in Virginia. If they could further imagine a very law-abiding nation, where punishment surely followed breaches of the Mines Act, they would begin to see that a manager's first duty was to keep within the law, and that initiative and originality followed—a short or a long distance behind.

(3) In this country both a Minimum Wage Act and an Eight Hours' Act were in force. Moreover, it was a fact that in some parts no miner until recently was allowed by his union to work more than 5 days per week. This was now altered to 11 days per fortnight in Scotland, and included, of course, a short day on Saturday. American mining engineers would readily understand that, even if British conditions were as favourable as their own and the practice as good, labour was less efficient, and (even at lower wage rates) was dearer than in America, whilst the result was a lower output per man. All these facts implied that a keen eye must be kept on cheap forms of labour, such as boys and elderly men, as these could handle small trams on drawing-roads and haulage termini, but would be less useful if large trams were in use.

In the case of seams from 18 to 30 inches in thickness, in addition to the ever-present problem of haulage from the face, the prime necessity was, so far as he could see, to advance the faces as

rapidly as possible and to handle a minimum amount of dirt. The coal-cutter and conveyor was the remedy that first suggested itself, but the sphere of usefulness of these machines was limited. For example, electric power could not be used in a fiery seam, and the employment of compressed-air plant in so small a working that was advancing rapidly was a matter of difficulty. Again, tender roofs, soft floors, and troubled ground frequently required tackling by manual labour.

If the seam was rising, say, 1 in 6 or 1 in 9, dip stowage for the dirt was soon filled, and rise stowage was slow and expensive. Where the gate-roads were 12 yards apart, the amount of surplus dirt was increased, while if 18 yards apart the output per lineal yard of face was decreased; consequently, the rate of advance also was decreased, much trouble was caused in a weak roof, and the percentage of small coal was increased.

The sending of dirt to bank during the day-shift might interfere with the handling of coal; whilst its transport by night involved the provision of haulage attendants, bottomers, banksmen, etc.—a matter of no great difficulty at a large colliery, but of serious importance at a small mine. After the dirt had gone to bank, rent must be paid (perhaps for ever) for the ground that it occupied; and, as the tip-heap extended, mechanical transport was required, with attendants to handle the dirt.

American mining engineers might, in view of these circumstances, be little surprised if British mining engineers, either by a process of logic or from a habit of compromise, concluded that, after everything had been taken into consideration, as little dirt as possible should be handled, and that the trams must be of such a size as this consideration, when weighed against the haulage factor, might determine.

Mr. H. F. Bulman (Newcastle-upon-Tyne) wrote that Mr. Gibson was to be congratulated on his original treatment of a subject which had perhaps hitherto been governed too much by custom and rule of thumb.

The economic advantages arising from the standardization of the coal-tub and the track could hardly be denied, and there seemed to be no sufficient reason why a few standard sizes should not meet all the requirements of the coal-mines of this country just as well as the present enormous and anomalous variety.

The purpose of the tub and track was to convey the coal from the face to the shaft with as small an outlay on labour and materials as possible. As an outstanding fact, it was evident that the smaller the dead load (due to the weight and the friction of the tub) was in proportion to the useful load of coal carried, the better would this purpose be achieved. In this respect a big tub had an inherent advantage over a small one. But this was conditioned by the necessity, or perhaps it would be more accurate to say, the general custom, of man-handling the tub in moving it in the neighbourhood of the coal-face, at the shaft, and when it got off the way.

It might be remarked that modern progress in the shape of face-conveyors and auxiliary haulage had reduced (or even in some cases had abolished) the necessity of hand-putting. But, where the tub was moved by manual labour, economic considerations pointed to limitation of its weight to what could be moved by a strong lad employed at a wage of 3s. 9d. a shift—to take Mr. Gibson's figures—rather than by a man who received double that wage. The advantage of the small tub was confined almost entirely to its transit from the coal-face to the engine-plane landing in-bye.

Mr. Gibson stated that in thin seams the size of the tram governed the size of the road, but in practice there were many exceptions to this rule. Large trams were used in thin seams, and the size of the tram did not always, or perhaps generally, correspond to the size of the road. The cost of making and maintaining the roads from the face to the engine-plane landings was, of course, a main factor to be considered. Against this had to be set the economical advantage of the large tram in first cost and cost of maintenance, in reduction of dead load, and in simplifying the winding and banking arrangements. In the case of trams containing 2 tons of coal, a single-deck cage holding two trams would suffice for a load of 4 tons each journey; but with trams containing only 10 cwts., a double-decked cage would be required, plus additional time and labour for uncaging.

Besides the cost of making roads, there must also be taken into consideration the first cost of the tubs and the cost of maintaining them, as well as the cost of moving them between the coal-face and the screens. The balance of advantage had to be struck between these three sources of cost.

With regard to the gradient, it was irregularity rather than steepness of gradient that affected the question, because in seams of a regular steep gradient the system of working could be adapted to help the movement of the tubs.

Mr. Gibson had suggested nine different sizes of standard tubs. Was it necessary to have so many?

Mr. Myles Brown (Gateshead-upon-Tyne) wrote that his first impression after reading the paper was that some of the statements with regard to the present practice in mines were a little rash and overdrawn. In seeking further evidence from a well-known firm in Sheffield, who were perhaps the largest manufacturers of tram-wheels, etc., the information given fully supported Mr. Gibson in his contention, and, as the evidence of such a firm was of general interest, he gave their statement of the case, as follows:—

"We can only confirm the assertion made by the writer of the paper in regard to the numerous types of trams, etc., in use throughout Great Britain. In fact this is for us, as manufacturers, one of the greatest difficulties with which we have to contend. No attempt whatever seems to have been made either to standardize the size of the wheels, the capacity of the trams, or the track-gauge; the result is that to-day we have thousands of wheel patterns, some of which vary only $\frac{1}{8}$ inch in diameter and width of tread, and even less than this in the depth and thickness of the flange.

"There are scarcely two mines in the country using the same wheel, and similar trouble is experienced in connexion with the track-gauge and the pedestals, with the result that it is absolutely impossible for us to carry stocks with any degree of certainty that we shall be able to dispose of them. Consequently, the requirements of the collieries can only be filled on definite orders, and from time to time our friends find themselves in very serious difficulty, due to the forgetfulness of the official who is responsible for seeing that their stocks are maintained. We know that, so far as old-established collieries are concerned, it may be a difficult matter to introduce any alteration to the trams or track; but we do feel that, in the opening-out of new collieries, something more might be done in the direction of standardization, with advantage both to the colliery-owners and to the manufacturers."

Standardization was generally accepted to stand for economic production. Whilst the box or body of the tram did not itself provide ground for a great saving by the adoption of a standard design or size, yet the component parts, such as the wheels, axles, pedestals, etc., provided a great opportunity for standardization of design and size.

Before any attempt was made to systematize and standardize design and size, complete information as to the types and sizes at present in service, and the environment and conditions under

which each particular tub or tram worked, should be collected and put in handy form for the consideration of those interested.

The present time was not opportune for carrying through any new work which involved extensive investigations; but, in case the suggestion might in the future be of service, the proposal was put forward for the formation of a strong representative standardization committee, the members of which should consist of delegates both of mining and mechanical engineers and of manufacturers. The work of this main committee would be to consider the tabulated data, giving details of present-day practice, and then to direct the work of standardization. The collection of the tabulated practical data could be carried through by a contributory committee, consisting of colliery managers and engineers, who, no doubt, could readily tabulate much useful information in regard to the size and design of the plant which was under their supervision.

The work of these committees would pave the way for improvements which would add considerably to the efficiency of the mining industry, and aid materially in pushing forward and defending our lines in the great industrial and commercial rivalry which would doubtless become more intense immediately the present armed conflict ceased.

Standardization would eventually find a much wider field. A subject which the writer had for many years put forward for standardization and better classification was the raw material "coal." It was of national importance, and a reasonable demand from the standpoint of the nation's economics that all coal should be consumed or applied to use under conditions which produced to the industry concerned and to the nation at large the utmost value obtainable from the coal in question. Coal should be standardized according to its suitability (chemical and physical) for any particular purpose or purposes.

Mr. Gibson's paper might well be the starting-point of investigations which would in the near future prove a boon to the mining industry.

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Mr. A. S. BLATCHFORD'S paper on "The Influence of Incombustible Substances on Coal-dust Explosions" was taken as read, as follows:—

# THE INFLUENCE OF INCOMBUSTIBLE SUBSTANCES ON COAL-DUST EXPLOSIONS.

By A. S. BLATCHFORD, M.Sc.

It has been known for some years past that, by mixing incombustible solid matter with coal-dust, the inflammation of the dust in a coal-dust-and-air explosion has been retarded. The present experimental work, which is a development of Dr. Bedson's previous investigations,* was undertaken to observe the quenching effect of different substances, to find the most efficient of these substances, and to arrive at a possible explanation of their preventive action.

*Apparatus.*—The explosions were carried out in a form of explosions-vessel previously described,† which is a strong spherical glass vessel of a capacity of about 120 cubic inches. It is provided with three tubulures; the upper one carries the means of ignition, the second serves for the introduction of the coal-dust, whilst to the third can be attached some appliance for ascertaining the impulse produced by the explosion. The means used for this latter purpose was a device described by Teclu, and employed by him in his investigation of the purity of illuminating-gas.

The essential part of the apparatus consists of a pendulum suspended from a brass frame. To the end of the pendulum is attached a small aluminium basin, which fits lightly but well over a brass tube, 1 inch in diameter, attached by a rubber collar to the end of a glass tube, 15 to 16 inches long and 1½ inches in diameter, attached at its other end by means of a rubber collar to the third tubulure of the explosions-vessel. The pendulum

* "Experiments Illustrative of the Inflammability of Mixtures of Coal-dust and Air," by Prof. P. Phillips Bedson and Mr. Henry Widdas, *Trans. Inst. M. E.*, 1906, vol. xxxii., page 529; 1907, vol. xxxiv., page 91; and "Experiments Illustrative of the Inflammability of Mixtures of Coal-dust and Air," by Prof. P. Phillips Bedson, *ibid.*, 1910, vol. xxxix., page 719; and 1911, vol. xli., page 235.

† *Ibid.*, 1906, vol. xxxii., page 529.

moves over a graduated arc, and to it is attached a simple arrangement fitted into a ratchet on the upper part of the graduated arc, so that the pendulum is arrested in the position to which it is forced by the impulse acting on the concave side of the basin. A quenched explosion would be indicated by the stationary position of the pendulum.

A Nernst filament, giving a temperature of 1,500° to 2,000° Cent., was used as a means of ignition. The filament was heated by a Bunsen burner to a temperature sufficiently high for it to conduct the electric current, and then introduced into the explosions-vessel through the upper tubulure.

*Experimental.*—The coal-dusts experimented with were such as passed through a 100-mesh sieve (10,000 holes to the square inch), and were obtained by grinding the coals. The quenching substances were used in as fine a state of division as possible. A weighed quantity (1 gramme) of the mixture of quenching substance and coal-dust, mixed in known proportions, is placed in the tubulure of the explosions-vessel, which is closed by a tightly-fitting rubber stopper carrying a tube connected with a compressed-air supply (atmosph. + 12″ to 14″ Hg). The filament is then placed in position, the coal is projected by the blast of air over the glowing filament, and the impulse communicated by the explosion is indicated by the extent to which the pendulum is deflected. By using the same mixture and igniting it at practically the same temperature, fairly concordant results have been obtained. About four to six separate explosions were necessary in the case of each different mixture. The explosions were carried out in groups of three, the filament being extinguished, the apparatus allowed to cool, and then cleaned out between each three. The ratio of the quenching substance to coal was varied, and Table I. records the least percentage of quenching substance in the mixture which prevents an explosion; Table II. records the specific heats of the materials used; Table III. gives the thermochemical data; whilst Table IV. contains miscellaneous information regarding the behaviour of the quenching materials at high temperatures.

The quenching materials used were gypsum, dried Chance mud, quicklime, magnesia, magnesia alba (levis), anhydrous sodium carbonate, sodium bicarbonate, soda-crystals, Glauber

salts, ground shale, and boiler-ashes. The anhydrous sodium carbonate was obtained by strongly heating the bicarbonate. The boiler-ashes were ground from the ashes of a boiler fire burning coke. The soda-crystals and Glauber salts were used with as much water of crystallization as was consistent with a fine state of division. They were obtained by making a saturated solution of the ordinary variety in warm water, rapidly cooling the solution from a moderate temperature, drying the crystalline product, and grinding it. The friction produced during grinding tended to give heat, and liberated some of the water of crystallization. A specimen of the salt as used in the experimental work was afterwards subjected to analysis, in order to determine the proportion of water of crystallization present in it.

TABLE I.—THE LEAST PERCENTAGE OF QUENCHING MATERIAL IN THE MIXTURE WHICH PREVENTS AN EXPLOSION.

| Coal ... ... ... ... ... | A | B | C | D |
|---|---|---|---|---|
| Boiler-ashes ... ... ... ... | 57 | 50 | 47 | 58-60 |
| Quicklime ... ... ... ... | 50 | 45 | 42-44 | 55 |
| Ground shale ... ... ... ... | 43 | 37 | 35 | 46 |
| Chance mud ... ... ... ... | 38-40 | 30-33 | 29-30 | 39-40 |
| Gypsum ... ... ... ... | 33-35 | 26-28 | 26 | 35 |
| Magnesia ... ... ... ... | 28-30 | 28 | 25-26 | 32-33 |
| Magnesia alba (levis) ... ... | 22 | 17-19 | 15 | 22-23 |
| Anhydrous sodium carbonate ... | 12-13 | 10+ | 12 | 15 |
| Soda-crystals ... ... ... ... | 10 | 10− | 9+ | 11 |
| Sodium bicarbonate ... ... ... | 9-10 | 7 | 7 | 8− |
| Glauber salts ... ... ... ... | 8 | 8 | 7− | 8− |

TABLE II.—SPECIFIC HEAT OF MATERIALS USED.

| | |
|---|---|
| Quicklime ... ... ... ... ... ... ... | 0·19 |
| Chance mud ... ... ... ... ... ... ... | 0·22 |
| Gypsum ... ... ... ... ... ... ... | 0·24 |
| Magnesia ... ... ... ... ... ... ... | 0·23 |
| Magnesia alba (levis) ... ... ... ... ... | 0·26− |
| Anhydrous sodium carbonate ... ... ... ... | 0·27 |
| Soda-crystals ($5H_2O$) ... ... ... ... ... | 0·35 |
| Sodium bicarbonate ... ... ... ... ... ... | 0·30 |
| Glauber salts ($6H_2O$) ... ... ... ... ... | 0·34 |

TABLE III.—THERMOCHEMICAL DATA.

| | |
|---|---|
| $CaCO_3$ ... ... | Requires 42·52 K for gramme-molecule decomposition. |
| $CaSO_4, 2H_2O$ ... | Requires 4·84 K to drive off $2H_2O$ per gramme-molecule. |
| $Na_2CO_3, 5H_2O$ ... | Requires 12·364 K to become anhydrous. |
| $Na_2SO_4, 6H_2O$ ... | Requires 11·52 K to become anhydrous. |
| $2NaHCO_3$ ... | Requires 30·73 K to become sodium carbonate. |

K = 1,000 calories.

TABLE IV.—MISCELLANEOUS INFORMATION REGARDING THE BEHAVIOUR OF QUENCHING MATERIALS AT HIGH TEMPERATURES.

| | |
|---|---|
| Gypsum ... ... | Loses $2H_2O$ at 120°-130° Cent., becoming anhydrous. |
| $CaCO_3$ ... ... | Commences to decompose at 550° Cent. |
| MgO ... ... | Melts at 2,250° Cent. (no decomposition). |
| Lime ... ... | Melts at 1,900° Cent. (no decomposition). |
| Magnesia alba (levis) | Converted to magnesium carbonate by 200° Cent., afterwards decomposes, giving off $CO_2$. |
| $NaHCO_3$ ... ... | At a dull-red heat is converted to $Na_2CO_3$. |
| $Na_2CO_3$ ... ... | Melts at 1,098° Cent. (no decomposition). |
| $Na_2CO_3, 10H_2O$... | Loses 5 molecules at 12·5° Cent. |
| | Loses 9 molecules at 38° Cent. |
| | Becomes anhydrous at 87° Cent. |
| $Na_2SO_4$, xHO ... | Loses all its water of crystallization by 100° Cent. |
| $Na_2SO_4$ ... ... | Melts at 863° Cent. |

*Influence of Carbon Dioxide derived from Decomposition of a Quench.*—Both calcium and magnesium carbonates are decomposed by heat (under the experimental temperature), with liberation of carbon dioxide, yet the critical percentages of these carbonates are greater than that of sodium carbonate, which may fuse but is not decomposed (except to a negligible extent by the carbonaceous matter present). Although the *Second Report of the Royal Commission on Explosions in Mines* suggests that carbon dioxide may be a determining factor in the quenching of an explosion, it is suggested from this experimental work that the liberation of carbon dioxide from a quench has but small influence on the explosive character of a mixture. Sodium bicarbonate gives a low critical percentage and is decomposed by heat, yielding the carbonate ($2NaHCO_3 = CO_2 + Na_2CO_3 + H_2O$), with liberation of carbon dioxide. The temperature of the decomposition is comparable with that of the decomposition of calcium carbonate; but a possible explanation—other than the carbon-dioxide hypothesis—of the much greater efficiency of sodium bicarbonate will be given below. A comparison of calcium carbonate and gypsum will show that, so far as decomposition with liberation of an incombustible gas is concerned, water (as steam) is more effective than carbon dioxide (44 per cent. $CO_2$ in calcium carbonate; 20·9 per cent. $H_2O$ in $CaSO_4$, $2H_2O$).

*Influence of a Quenching Material from Specific-heat Considerations.*—A direct comparison of the action of quicklime and magnesia will show that the difference between the behaviour

of these compounds is explained most satisfactorily on the hypothesis that the specific heat of the quenching substance is the important factor in its efficiency. A comparison of the action of sodium bicarbonate (7 per cent.) and that of anhydrous sodium carbonate (12 per cent.) also supports the specific-heat hypothesis —assuming that the carbon-dioxide production has little effect. On the basis of efficiency due to carbon-dioxide liberation, calcium carbonate (yielding 44 per cent. of its weight as carbon dioxide) would be almost an ideal quenching substance.

*Influence of Water of Crystallization.*—The hydrated sodium carbonate has greater specific heat than the anhydrous variety; but the greater efficiency of the soda-crystals may be due to the water liberated by dehydration during the rise of temperature. In experiments with one coal, mixtures of (*a*) 85 per cent. of coal and 15 per cent. of anhydrous carbonate, and (*b*) 89 per cent. of coal and 11 per cent. of soda-crystals, are incombustible. The 11-per-cent. soda-crystals are resolved into 6 per cent. of sodium carbonate and 5 per cent. of water-vapour. These soda-crystals contain 46 per cent. of water of crystallization. It is evident that there may be some preventive action in the liberated water-vapour.

Increase of specific heat accompanies increase of the number of molecules of water of crystallization, so that it is necessary to determine which is the essential factor—the specific heat or the water. The experiments with sodium bicarbonate show that it is as efficient as Glauber salts. The bicarbonate remains stable up to about 600° Cent. (specific heat, 0·30), whilst the Glauber salt has a specific heat of 0·34, which falls at 100° Cent. to 0·24. From a comparison of the properties of these two compounds, it is suggested that specific heat is the factor which determines efficiency, and that water of crystallization is to be considered mainly in that it gives an increase in specific heat to hydrated compounds above the anhydrous compounds from which they are derived. The soda-crystals contained 46 per cent. of water of crystallization; the Glauber salts, 43 per cent.; yet the latter substance is slightly more efficient than the former (8 per cent. and 10 per cent. respectively). The specific heat of the hydrated varieties are about the same (0·35 and 0·34), that of anhydrous sodium sulphate 0·24, and that of anhydrous sodium carbonate

0·27. The specific-heat hypothesis seems, therefore, to break down; but it is suggested that during the rise of temperature to the firing-point the sodium sulphate remains hydrated for a longer time than the sodium carbonate, and then the influence of the high specific heat of the hydrated Glauber salts is noticed.

*Influence of the Heat of Reaction.*—In reviewing the conclusions, it is of interest to note the range of temperature during which the quenching action seems to take place. In the case of one coal the effect of 28 per cent. of magnesia is equal to the effect of 8 per cent. of Glauber salts. After losing water of crystallization by 100° Cent., Glauber salt has a specific heat of 0·24. Neglecting for the moment the heat effect during the rise to dehydration temperature of Glauber salts from 100° to 800° Cent. (about the firing temperature of the coal), we have two mixtures behaving alike, namely:—

(*a*) 28 parts of magnesia of specific heat 0·23, and 72 parts of coal of specific heat 0·24.

(*b*) 4 parts of anhydrous sodium sulphate of specific heat 0·24, and 92 parts of coal of specific heat 0·24.

The specific heat of coal may be taken as about 0·24.

The suggestion arises that the heat-absorption from 0° to 100° Cent. (that is, during the dehydration of the Glauber salts) is a most effective factor in determining the low percentage of this material as a quenching substance.

The heat of reaction is of the same order of magnitude as the heat absorbed by specific heat requirements:—

250 grammes $Na_2SO_4, 6H_2O$ require 11·52 K for dehydration.
100 ,, $Na_2SO_4, 6H_2O$ require 4·61 K for dehydration.
100 ,, $Na_2SO_4, 6H_2O$ require 3·5 K for a rise through 100° Cent.
100 ,, $Na_2SO_4$ anhydrous require 2·4 K for a rise through 100° Cent.
56 ,, $Na_2SO_4$ anhydrous require 1·4 K for a rise through 100° Cent.

The specific-heat hypothesis now modifies itself into one of "heat absorption," in which both (1) heat required for decomposition, and (2) heat required for rise in temperature, are to be taken into account.

The heat required thermochemically by the soda-crystals is also notable:—

100 grammes $Na_2CO_3, 5H_2O$ require 6·3 K for dehydration.
100 ,, $Na_2CO_3, 5H_2O$ require 3·55 K for a rise through 100° Cent.
53 ,, $Na_2CO_3$ require 1·43 K for a rise through 100° Cent.

The effect of a quench is probably due to the rate—as implied in the conception of specific heat—of heat-absorption over a particular range of temperature, and depends not merely so much upon the total heat effect.

The fact of there being an explosion of a dust—as well as the force produced by an explosion—would depend partly on the velocity of the rise of temperature; a quenching material would be most efficient when it prevents a rapid rise of temperature by large heat-absorption comparatively early in the rise of temperature—say in the rise from 0 to 100 degrees if the coal fired at 800° Cent.

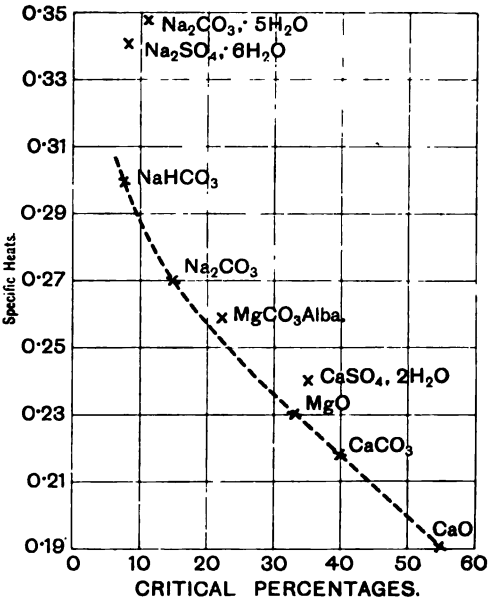



FIG. 1.—CURVE SHOWING THE RELATION BETWEEN THE SPECIFIC HEATS AND THE CRITICAL PERCENTAGES FOR ONE OF THE COALS TESTED.

Chance mud requires heat for heat of reaction, but not until 550° Cent., which is too near the explosion temperature of the coal: for, by the time that this point has been reached, the velocity of the rising temperature is too great for the thermo-chemical effect of the decomposing calcium carbonate to be of much value. A reaction involving liberation of carbon dioxide may be of use in quenching the explosive character of a dust if the carbon dioxide is all given off by 200° Cent. From 130° Cent. upwards anhydrous calcium sulphate (specific heat, 0·20) is apparently more efficient than Chance mud (calcium carbonate; specific heat, 0·25), thus supporting the suggestion of the action of a quench taking place during the first 200 degrees of rise.

It may be suggested that the action of solids which liberate a large percentage of water of crystallization is due to the mechanical effect of the free gases blowing the dust away from the

igniting medium and keeping the coal out of the sphere of action. Reference to the properties of sodium bicarbonate and its efficiency will meet this objection; moreover, if the effect were mechanical, still smaller percentages of quenching materials would probably be required.

No experiments were carried out with incombustible or combustible gases in the apparatus; but, presumably, this could be accomplished by mixing the gases to be applied with the blast of air blowing the dust over the igniting medium. Nothing is said at present with regard to the difference between the coals.

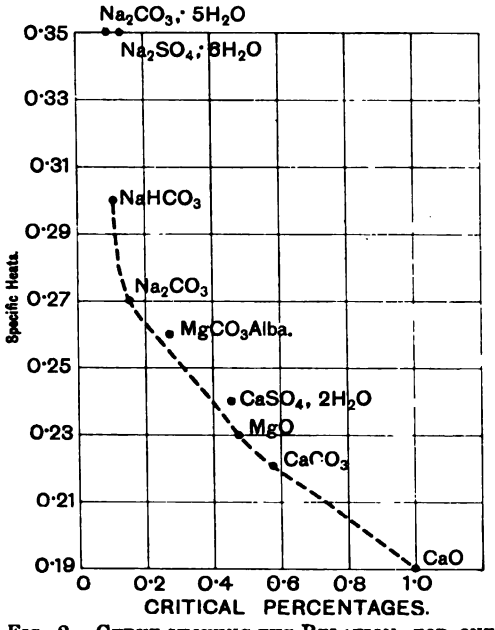



Fig. 2.—Curve showing the Relation, for one of the Coals tested, Between the Specific Heats and the Critical Percentages based on Lime as a Unit.

The figures given in the paper are only approximate, and must not be taken as exact.

The curve (Fig. 1) shows the relation between the specific heat and the critical percentages for one of the coals. The hydrated quenches all lie on the same side of the curve, but off it in such a way that their critical percentages would be much smaller if these bodies retained their original compositions and specific heats over a long range of temperature. No correction is here introduced in the curve for thermochemical heat-absorption; and this may explain the anomalous position of the hydrated quenches, or their anomalous position may be due to an overestimate of the specific-heat effect of added water.

*Supplement* (Fig. 2).—Lime was found to be one of the least effective of the quenching substances, and the supplementary table shows the values calculated (in lime as a unit) for the rela-

tive weights of materials required, the lime unit being, of course, different for the different coals:—

| Coal | A | B | C | D |
|---|---|---|---|---|
| Boiler-ashes | 1·32 | 1·22 | 1·18 | 1·17 |
| Quicklime | 1·00 | 1·00 | 1·00 | 1·00 |
| Ground shale | 0·75 | 0·72 | 0·71 | 0·69 |
| Chance mud | 0·66 | 0·58 | 0·56 | 0·54 |
| Gypsum | 0·5 | 0·45 | 0·46 | 0·44 |
| Magnesia | 0·42 | 0·47 | 0·44 | 0·39 |
| Magnesia alba (levis) | 0·28 | 0·27 | 0·23 | 0·23 |
| Anhydrous sodium carbonate | 0·156 | 0·15 | 0·19 | 0·14 |
| Soda-crystals | 0·105 | 0·091 | 0·10 | 0·07 |
| Sodium bicarbonate | 0·11 | 0·13 | 0·13 | 0·10 |
| Glauber salts | 0·09 | 0·087 | 0·10 | 0·07 |
| Proportion of coal | 1·00 | 1·22 | 1·32 | 0·82 |

Mr. A. S. Blatchford (Armstrong College, Newcastle-upon-Tyne) said that he would like to preface his paper with two observations—first, that the paper was mostly of theoretical interest, and it was now left to the practical engineers to co-operate with the Universities in applying the underlying principle as explained in the paper; secondly, three-fourths of the work had been done before the war commenced, but, owing to the great difficulty of completion, it had not been possible to put the results before the Institute earlier. The original idea emanated from some remarks made by Prof. Louis, to whom he was indebted, and also to Prof. Bedson for his valuable help.

Prof. P. Phillips Bedson (Armstrong College, Newcastle-upon-Tyne) wrote that he was much interested in Mr. Blatchford's careful examination of the conditions which determined the action of different substances that could be employed as preventive agencies in coal-dust-and-air explosions. It was very evident that the mode of action of these "quenches" was by no means a simple matter, and the facts brought forward showed that chemical decomposition of the quench by heat was quite a subordinate influence, if an influence at all. It would appear that the action was physical rather than chemical.

Mr. T. W. D. Gregory (Central School of Science and Technology, Stoke-on-Trent) wrote that the author had stated that "the effect of a quench is probably due to the rate . . . of heat-absorption over a particular range of temperature, and depends

not merely so much upon the total heat effect; " and, again, that " a quenching material would be most efficient when it prevents a rapid rise of temperature by large heat-absorption comparatively early in the rise of temperature—say in the rise from 0 to 100 degrees if the coal fired at 800° Cent." It would appear from the various tables given in the paper, or from calculations made from the figures, that if 100 grammes of each of the following substances be taken, namely, gypsum, anhydrous sodium carbonate, soda-crystals, sodium bicarbonate, and Glauber salts, and an initial rise in temperature of 200° Cent. be assumed, also the maximum specific heat to obtain in each case throughout the rise, and intermolecular change being ignored—the amount of heat absorbed would be as under:—

A.

| | |
|---|---|
| Gypsum ... ... ... ... ... ... ... | 4·8 K. |
| Anhydrous sodium carbonate ... ... ... ... | 5·4 K. |
| Soda-crystals ... ... ... ... ... ... | 7·0 K. |
| Sodium bicarbonate ... ... ... ... ... | 6·0 K. |
| Glauber salts ... ... ... ... ... ... | 6·8 K. |

In several of these substances, however, intermolecular changes were taking place, which required heat just as much as heat was necessary to bring about a rise in temperature. For 100 grammes of each substance before mentioned, the measure of this heat—the same range of rise of temperature being assumed—would be as follows:—

B.

| | |
|---|---|
| Gypsum ... ... ... ... ... ... ... | 2·81 K. |
| Anhydrous sodium carbonate ... ... ... ... | Nil. |
| Soda-crystals ... ... ... ... ... ... | 6·31 K. |
| Sodium bicarbonate ... ... ... ... ... | Nil. |
| Glauber salts ... ... ... ... ... ... | 4·61 K. |

The remarks already quoted from the paper showed that these figures must be material in estimating the heat absorbed in the early stages of the rise of temperature. For example, the heat absorbed by equal weights of soda-crystals and sodium bicarbonate (taking the sum of Tables A and B) were respectively 13·31 K. and 6·0 K., and yet it would be found from the author's Table I. that the sodium bicarbonate was the more efficacious. Again, gypsum (weight for weight with anhydrous sodium carbonate) absorbed 7·61 K, compared with 5·4 K, and yet the experimental data adduced showed that the anhydrous sodium carbonate was

very considerably the superior deterrent. Without going further, it would appear that the conclusions arrived at by the author with regard to the value of the specific-heat factor were anything but proved.

He (Mr. Gregory) would, moreover, like to mention a point which appeared to have been overlooked. In the case of those substances which contained combined water, the heat of dehydration did not include the heat necessary to vaporize the water separated, that was, the latent heat. Before the temperature could pass beyond the boiling-point, each gramme of water separated must be converted into steam, and this required per gramme of water at 100° Cent. 0·537 K.

Calculations for the substances already mentioned showed that the following additional amounts of heat must be absorbed by the 100 grammes of each within the range of temperature dealt with:—

| | C. | |
|---|---|---|
| Gypsum ... ... ... ... ... | | 11·22 K. |
| Anhydrous sodium carbonate ... ... | | Nil. |
| Soda-crystals ... ... ... ... | | 24·65 K. |
| Sodium bicarbonate ... ... ... | | Nil. (Not decomposed within range taken). |
| Glauber salts .. ... ... ... ... | | 23·2 K. |

Summarizing the various absorptions of heat for these substances, the following figures were arrived at:—

| | A. | B. | C. | Total heat. K. |
|---|---|---|---|---|
| Gypsum ($CaSO_4$, $2H_2O$) ... ... ... | 4·8 | 2·81 | 11·22 | 18·83 |
| Anhydrous sodium carbonate ($Na_2CO_3$) | 5·4 | — | — | 5·4 |
| Soda-crystals ($Na_2CO_3$, $5H_2O$) ... ... | 7·0 | 6·31 | 24·65 | 37·96 |
| Sodium bicarbonate ($NaHCO_3$) ... | 6·0 | — | — | 6·0 |
| Glauber salts ($Na_2SO_4$, $6H_2O$) ... ... | 6·8 | 4·61 | 23·2 | 34·61 |

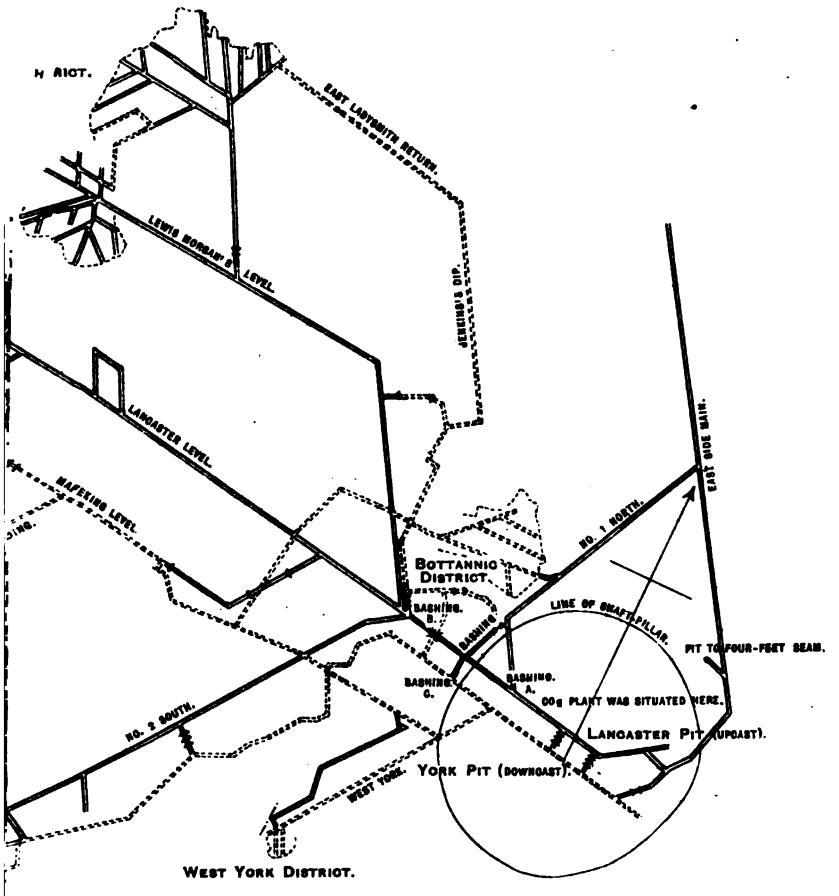
Since anhydrous sodium carbonate and sodium bicarbonate required relatively such small amounts of heat to raise their temperatures in the initial stages, it was certainly curious that they should occupy so favourable a position in Table I. A probable explanation was that the last four substances in Table I. --the most effective deterrents by some considerable margin— all fused at temperatures which under the conditions of the experiment would be quickly reached. It was conceivable, therefore, that coal-particles when mixed with these substances became coated with a film of non-combustible liquid which pre-

vented or retarded combustion. The other substances in the list, however, would remain solid at the temperatures reached, and consequently hinder but little the process of combustion.

He had for some years advocated the use of potash alum as a deterrent; for many reasons he considered it more suitable than any other substance. It contained large quantities of combined water, which, unlike many other substances, such as soda-crystals, it could retain for long periods at the ordinary mine temperature. It absorbed large quantities of heat, owing to the fact that heat was required to dehydrate the substance, as well as to vaporize the water liberated. It also became liquid on heating, and tended to coat or film the substance in contact with it.

Mr. J. D. MORGAN (Birmingham) wrote that the results confirmed what had hitherto been more or less generally believed, but had not, so far as he knew, been established by a systematic investigation, namely, that, apart from considerations of cost and convenience, the usefulness of an inert dust in diminishing or preventing a combustible dust explosion depended upon its capacity for heat and the rate at which heat could be absorbed by it. Excepting decomposible inert dusts, those properties depended upon specific heat and conductivity. The value of the paper would, in his opinion, be increased if the thermal conductivities of the materials mentioned could be given. He could scarcely agree with the author in his statement that the rate of heat-absorption was implied in the conception of specific heat. Rate belonged rather to conductivity. In the case of decomposible compounds, the effects of specific heat and conductivity were supplemented by, if not subordinated to, the heat-absorption in the process of decomposition. Expressed in general terms, the usefulness of the inert material depended upon its rate of and capacity for heat-absorption, a fact which was abundantly supported by the evidence adduced in the paper. It was interesting to see laid low the old fallacy concerning materials which gave off carbon dioxide when decomposed by heat. One still heard or saw repeated the statement that a dust capable of giving off that gas should be very effective in quenching a dust explosion. A little consideration was sufficient to show how slight was the justification for the belief. The carbon dioxide thus formed was practically a bye-product of the explosion, and consequently could not have any more

—SS SYSTEM OF VENTILATION BEFORE EXPLOSION.




REFERENCES.

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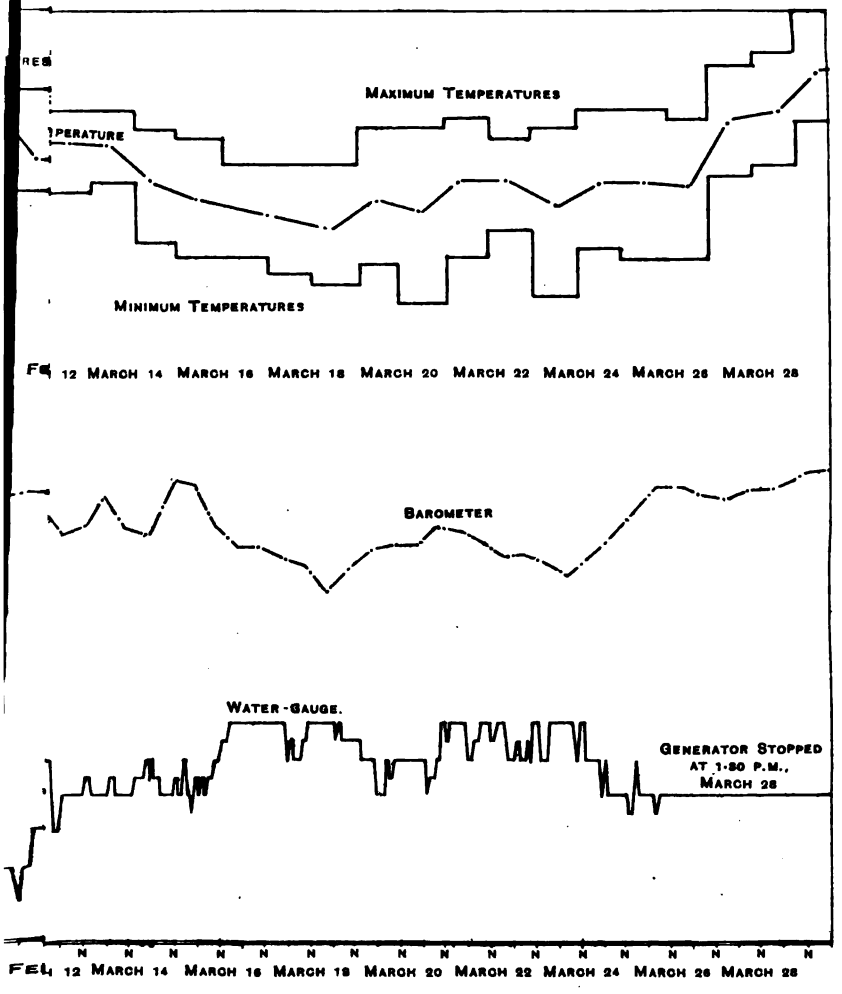
MAXIMUM TEMPERATURES
MINIMUM TEMPERATURES
BAROMETER
WATER-GAUGE.
GENERATOR STOPPED AT 1·30 P.M., MARCH 28
12 MARCH 14 MARCH 16 MARCH 18 MARCH 20 MARCH 22 MARCH 24 MARCH 26 MARCH 28

quenching effect than the carbon dioxide ordinarily produced in a coal-gas or dust-explosion.

It would be useful to have in Table I. the figures obtained in the tests on calcium carbonate, and he was sure that it would be worth while to add to the paper the figures or curves showing the effect on the explosibility of each or all of the coal-dusts of different quantities of the inert dusts employed.

Prof. HENRY LOUIS (Armstrong College, Newcastle-upon-Tyne) said they were very much indebted to Mr. Blatchford for the patience that he had shown in working out this very interesting branch of the subject, which certainly threw much light on the use of various substances in quenching explosions. Mr. Blatchford was quite right in remarking that the original idea of those investigations sprang from some remarks that he (Prof. Louis) had made when discussing papers by Mr. W. C. Blackett and Mr. R. Clive, in which he* compared the effect from the theoretical point of view of boiler-ashes and ground shale — from the point of view of their respective specific heats and of the heat absorbed by dehydration. He then predicted that any bodies that were capable of giving off moisture at a low temperature, and thus capable of absorbing a good deal of heat, would be better quenchers than anhydrous substances like boiler-ashes or sand. It was a matter of great gratification to him that these theoretical conclusions had now been proved by practical experiments to be correct.

The explanation of the figures given by Mr. Blatchford was not very simple, and he (Prof. Louis) ventured to think that Mr. Blatchford had overlooked one of the conditions which probably might explain some of the anomalies in his tables, namely, the degree of fine division of the particles, which might account for the puzzling fact that magnesia was a much more efficient quencher than quicklime. He would like to know whether the dimensions of these particles could not be determined. It was quite obvious that their quenching effect must be a function of their size. The heat was absorbed from the surface, and obviously the smaller the particle was, the greater would be the proportion which the surface bore to the mass of the particle, so that the fineness of division played an important part from that

* *Trans. Inst. M. E.*, 1913, vol. xlv., page 318 ; and 1914, vol. xlvii., page 404.

point of view. They were very much indebted to Mr. Blatchford and Prof. Bedson for having done this work and given them this further addition to the lengthy series of scientific data which the laboratories of Armstrong College had been able to furnish to the Institute.

The PRESIDENT (Mr. T. Y. Greener), in seconding the vote of thanks, said that he would like to know, from the point of view of the practical engineer, what these figures meant. Was he correct in thinking that the experiments showed that Glauber salts was the best quencher, and that, as compared with boiler-ashes, for instance, the proportion in volume which would be necessary would be as 0·09 to 1·32?

Mr. BLATCHFORD replied that the figures represented the proportions by weight.

The PRESIDENT said that obviously went to show that, if it were possible to use Glauber salts, the quantity which would have to be used to make a mine immune from explosion would be very much smaller than in the case of boiler-ashes; but one would have to consider the relative costs of the two substances, and whether it would be worth while to go to the expense of purchasing Glauber salts, or to use stone-dust, which might be had for nothing.

Mr. WILLIAM SEVERS (Beamish) said there was no doubt that the paper did give them some idea of the relative quenching properties of the different substances, but he did not think that the conditions were the same as those that obtained in the pit. He understood that Mr. Blatchford had introduced into his experimentation vessel a certain amount of coal-dust, together with a certain amount of quenchers, and these had been mixed together in certain proportions. In the pit the conditions were, however, quite different. They had roads dusted with a quencher—say, boiler-ashes, or flue-dust as they called it—then they had a deposit of fine coal-dust on the top of that, and probably they had in a week or two to redust the whole road, and by and by they got the whole place dusted, three, four, five, or six times with one layer on top of the other. The whole of this stuff was

lying then in a condition of rest on the floor and the sides of the galleries of the mine. They might have an explosion after that, but that explosion might probably be due to the fine dust in the pit having been mixed up with the air and having set up certain conditions that were conducive to an explosion. If there were an explosion, the blast might come out-bye, but whichever way it went it raised the whole of this dust, so that the conditions prevailing were quite different in such circumstances from the conditions prevailing in the tests made by Mr. Blatchford; in fact, there was no comparison between the two. Coal-dust had a specific gravity of 1·25, but shale-dust would not rise with the same rapidity as coal-dust; consequently all the coal-dust was raised in the air, and this was conducive to an explosion. He thought that Mr. Blatchford should endeavour to make his conditions similar to those obtaining in an ordinary pit, and then let the members know the results.

It seemed to him (Mr. Severs) almost impossible to use Glauber salts, owing to the expense, but they were glad to employ flue-dust, which they could not get rid of otherwise, and to take it down the pit to be used as a quencher by dusting it along the roads and galleries. They had not only to take into consideration the relative values of the quenchers, but their cost.

Mr. A. S. Blatchford, replying to the discussion, wrote that the quenching action of the non-combustible materials was complex; and the members who had contributed to the discussion agreed fairly well that the explanation was to be looked for in the physical rather than in the chemical properties of the quenching materials.

Mr. J. D. Morgan had suggested that the heat conductivity might possibly be of importance, and had asked for the inclusion of the conductivity values of the materials used. It was difficult to obtain reliable information regarding these values, but the figures which were known indicated that the differences in conductivity were not large enough to correspond with differences in quenching effect. The heat required to raise the temperature of 1 cubic centimetre of gypsum 1 degree was about 180 times the heat conducted across a cubic centimetre between faces differing in temperature by 1 degree. If the rapidity of the explosion and the relative smallness of the conductivities of compounds

were borne in mind, differences in preventive action due to differences in conductivity might be taken as small in comparison with differences due to heat-absorption.

Mr. T. W. D. Gregory had calculated and set forth in tables the heat required for various purposes during an initial rise of 200° Cent. In his (Mr. Blatchford's) opinion the 6·31 K in Table B required by the soda-crystals to liberate the water of crystallization was, on account of the greater part of it being required at 38° Cent., of greater consequence than the 7·0 K, which was approximately the heat required to raise the temperature of the same substance through 200° Cent., and to combine these numbers in simple arithmetical addition was hardly justifiable. He (Mr. Blatchford) made no attempt to combine these heat requirements in any mathematical way—certainly not by simple addition, as he was of the opinion that the expression obtained would be too complex to serve any useful purpose. In Table C the heats required to convert the liberated water into vapour were stated. In his (Mr. Blatchford's) opinion there was a special mechanical effect at the boiling-point. A cubic foot of water yielded about 1,700 cubic feet of steam. When the particles with their water came within the influence of the igniting medium, the production of steam from a part of the water would convey the particles out of the region of influence of the igniting medium, an idea which was foreshadowed in the paper. Moreover, the steam would contribute an atmosphere which was incombustible and a non-supporter of combustion. He considered that the values in Table C should be reduced to some fraction of the present numbers, and even then the combination of A, B, and C should not be by arithmetical addition. In Mr. Gregory's opinion the explanation was to be found in the fusibility of the inert substances. He had stated in Table C that sodium bicarbonate was not decomposed in the initial 200 degrees rise, and had assumed that Glauber salts, soda-crystals, and gypsum formed a fluid mixture or solution with the liberated water of crystallization. The bicarbonate yielded less than 10 per cent. of its weight as water above 200° Cent., and was converted into carbonate fusing at about 1,100° Cent.; and he did not agree with Mr. Gregory that, under the conditions of the experiment, sodium bicarbonate and anhydrous sodium carbonate were easily fusible or formed easily fluid mixtures. The coal-dust itself

**GEORGE MAY**

PRESIDENT OF THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS, 1896-1898.

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*Born on February 12th*, 1839, *and died on June 18th*, 1915.

*(Presented by The North of England Institute of Mining and Mechanical Engineers.)*

would fire before the fusion of the quench took place; it was only extreme coals that required 1,300° Cent. for a firing temperature, some firing as low as 800° Cent. If the last four substances in Table I. were to be regarded as easily fusible, then gypsum, with its water of crystallization, should also be so regarded, and, according to this point of view, gypsum should be a much better deterrent than the results indicated. Mr. Gregory considered it possible for the coal-particles to become coated with a film of non-combustible fluid. It was hardly conceivable that 5 grammes of water would form very protective films for the particles of 5 grammes of dehydrated salt and 90 grammes of coal. He (Mr. Blatchford) could quite see that films had a protective value, if there was enough fluid to provide a sufficient thickness of film, but in the experiments under consideration the protectiveness of any films produced was, he thought, of small importance.

Mr. Severs had stated that the initial arrangement in layers of coal-dust and flue-dust in the roads of the mine was destroyed when the dust was raised by the blast, whichever way it went; therefore it hardly mattered whether the initial arrangement was one of layers or one of an intimate mixture. In the apparatus when the mixture was projected into the explosions-vessel the particles would arrange themselves in the air somewhat according to their specific gravities, or rather according to their buoyancies, and this Mr. Severs supposed also to happen in the galleries. The conditions in the apparatus and in the gallery with regard to the raised dust were not so incomparable as Mr. Severs thought.

In reply to Prof. Louis, he (Mr. Blatchford) wished to say that every care was taken to obtain and use the materials in as fine a state of division as possible. No measurements of the sizes of the particles were made. Further experimental work would solve the problem raised, but he was of opinion that alterations in the relative proportions of the figures in Table I. would be slight.

He (Mr. Blatchford) had rigidly avoided economic considerations and questions of cost.

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# THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,
HELD IN THE WOOD MEMORIAL HALL, NEWCASTLE-UPON-TYNE,
JUNE 3RD, 1916.

PROF. HENRY LOUIS, VICE-PRESIDENT, IN THE CHAIR.

The SECRETARY read the minutes of the last General Meeting, and reported the proceedings of the Council at their meetings on May 20th and that day.

The following gentlemen were elected, having been previously nominated:—

MEMBER—

Lieut.-Colonel WILLIAM HENRY RITSON, V.D., Colliery Owner, Springwell Hall, Durham.

ASSOCIATE—

Mr. JOHN STOKER, Colliery Under-manager, 1, Office Street, Wheatley Hill, County Durham.

SUBSCRIBERS—

THE HARDY PATENT PICK COMPANY, LIMITED, Heeley, Sheffield.

## DISCUSSION OF MR. SAMUEL DEAN'S PAPER ON "MODERN AMERICAN COAL-MINING METHODS, WITH SOME COMPARISONS."*

Mr. SAMUEL DEAN (Delagua, Colorado, U.S.A.) wrote that, in taking the photograph for Fig. 3 (page 345), he had not selected an abnormal place, and he could, if necessary, have a dozen or more photographs taken showing timbered machine-faces.

* *Trans. Inst. M. E.*, 1915, vol. l., pages 179 and 388; and 1916, vol. li., pages 35 and 340.

At least 75 per cent. of the shortwall machines in use were moved between the working-places by the aid of the trailing-cable, and not through power derived from a bare trolley-wire. If novices understood that machines could be moved by means of an insulated cable, then general managers or agents should know that they could be moved quickly by that method if the mine-workings were so planned as to facilitate quick movement.

Mr. Hare had not described how his "failure" machine was moved, nor had he described the machine except to say that it was a bord-and-pillar or heading machine, and a heading machine might be the old-fashioned breast machine. It would appear desirable to settle one controversy at a time, and therefore he would suggest that the thick seams in Great Britain where the pitches were not heavy might be dealt with, and their outputs compared with similar seams in America where electricity was not used for coal-cutting. Mr. Hare had not given a plan or any data relating to the workings where the machine was an absolute failure, nor had the American operator made any statement.

The writer wished it to be understood that he had not intended to infer that British mining engineers were lacking in skill, as Mr. Greener appeared to suggest. He hoped that the members would make for themselves an interesting comparison of the statements of Mr. Hare, Mr. Tate, and Mr. Halbaum, and he asked them to decide to what conclusion an unbiassed investigator would come after studying those remarks.

Later on, he would be prepared to go into the question of output in thin seams with difficult pitches and bad roofs. Such seams were being worked in America; he knew of one seam 4½ feet thick, pitching 38 degrees, which was being worked on the longwall-panel method, where the output per man at the face was 7·43 long tons per shift of 8 hours, and coal-cutting machines were not used. The roof was very bad, and had to be timbered with collars and legs right up to the face. Airways had to be driven in the rock, as they would not stand in the coal.

He had referred to Bentley Colliery because the coal there was as easy to break down as many seams that were undermined by machines, and there was no necessity to use electricity in a mine of that description to increase the output per man.

## DISCUSSION OF MR. HIRAM H. HIRSCH'S PAPER ON "THE HIRSCH PORTABLE ELECTRIC LAMP."*

Mr. HIRAM H. HIRSCH (Philadelphia, U.S.A.), in reply to Mr. Percy L. Wood, wrote that he was quite confident that upon investigation it would be found that his lamp was the first portable battery cap-lamp for use in mines, the first outfit of which was installed and successfully operated about seven years ago; since then it had been developed and improved upon, in order to give absolute satisfaction with regard to efficiency, practicability, and durability. The lamps were in use in many of the largest coal-mines in the United States of America.

As to the capacity of the lamps for withstanding abuse, the Pittsburgh Buffalo Company, the North-Western Improvement Company, the Franklin Coal & Coke Company, the Pennsylvania Coal & Coke Corporation, the Woodward Iron Company, the Lehigh Coal & Navigation Company, and the Reading Coal & Iron Company, who had large installations of these lamps, all testified as to their strength and durability.

He quite appreciated the fact that an increase in the size of the battery would result in a lamp of higher efficiency, and give greater illumination: this was very easily accomplished by increasing the size and weight of the battery, say, 25 or 50 per cent., which would permit of the use of a lamp of higher candle-power. Amongst the advantages of the cap-lamp might be mentioned the fact that the user had the free use of his hands: the light was thrown wherever he turned his head, so that he always had the light in front of him.

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## DISCUSSION OF MR. JOHN GIBSON'S PAPER ON "THE LOGIC OF TRAMS."†

Mr. I. C. PARFITT (Jerome, Pennsylvania, U.S.A.) wrote that he heartily agreed with and commended the conclusions arrived at by Mr. Gibson with regard to standardization, although he differed from him as to the particular features of the tram that required standardization so as to render it capable of national adoption.

In the United States the subject of "trams" seemed to have received more attention in regard to their construction and

* *Trans. Inst. M. E.*, 1916, vol. li., pages 61 and 350.

† *Ibid.*, 1916, vol. li., pages 72 and 350.

the reduction of friction than to standardization either with respect to the dimensions of the body of the car or of the wheel base. The tendency in the United States had been to adopt the maximum of carrying capacity under any and all conditions, as he (Mr. Parfitt) had endeavoured to show in his remarks on Mr. Samuel Dean's paper.* This tendency was caused by the almost universal adoption of the electric system of haulage, which, for its successful economic operation, required strength in construction of the rolling-stock, and this could be more easily attained in trams of large than in those of small capacity when the cost of construction formed an important factor, as it necessarily did.

There was, however, one vital objection to the use of maximum-sized trams in electric haulage, namely, the limitation in speed and size of trips produced by the gradients of the haulage-roads, the present general construction of mine electric motors being such as to give a maximum of efficiency for power consumed on gradients varying from a dead level to one not exceeding 3 per cent. against the loads. An attempt had been made to operate successfully the electric locomotive on heavy grades by the introduction of what was known as the "rack-rail" motor, in which a sprocket-wheel, situated in the middle of the machine, acted upon a sprocket-rail laid in the middle of the track, thus enabling the machine to climb heavy grades regardless of frictional resistance. This machine, however, had not, as yet, come into general use.

The use of cars of large capacity, with their necessarily corresponding weight, had imposed an increased burden of labour upon the miner where the cars had to be man-handled in rooms opened on an ascending grade that amounted to practically 50 per cent. of the labour required in blasting and loading the coal. Where the grade dipped to the working-face, the motors, being equipped with reel ropes, could haul the loads to the entry. Animal haulage was sometimes employed to overcome the former condition, but the use of animals in conjunction with electricity was not to be recommended.

It would be presumptuous on his part to attempt to criticize adversely Mr. Gibson's paper, as the geological formation of the coal-seams and the methods of extraction were so widely different in the two countries as to present no particular feature in

* *Trans. Inst. M. E.*, 1915, vol. l., page 395.

common; hence comparisons in general, or in any one particular, would be as irrelevant as they would be injudicious, as he had no knowledge of English mining conditions and methods beyond that derived from reading and from hearsay. Any comments and suggestions that he offered in the present remarks might be regarded as more applicable to the conditions and methods prevailing in the United States than to those in Great Britain, except, perhaps, such as were of so general a character that they might be of general application.

It appeared to him that the standardization of trams under conditions such as he was informed existed in Great Britain, where several seams of coal were developed from the same shaft, the seams differing materially in height and in the composition of the contiguous strata, would result in all the advantages and benefits claimed by Mr. Gibson.

Mr. Gibson had made certain statements relative to the determinating factors in the size of trams that were of so general and application that they might be regarded as universal, and, as such, he would take the liberty of commenting upon them.

Mining engineers and managers were neither harassed nor embarrassed in the United States by such a variety of nomenclature in mining terms as existed in Great Britain. The mining community in America consisted of so heterogeneous a composition of all nationalities that a common nomenclature had been made necessary by the very existence of this composite character. A "tram" in the United States was familiarly characterized by the name of "car" or "mine-car." The adjunct in the latter name was a distinctive appellation, so as to distinguish between the inside and outside rolling-stock: the latter was commonly designated as "steels" or "flats," the one term designating the composition and the other the form. The parallel steel lines on which the cars ran were known as the "track," and the bed on which the track was laid was known as the "road." Sleepers were known as "ties," and the term had a distinctive significance, since they were the implements by which the rails were bound or tied together and supported and maintained at the specified distance (gauge) apart.

Under the section "What Governs the Size of the Tram" it was stated that (other considerations apart) the greater the distance was the larger the tram should be. This was theoretically,

incontrovertible aside from the parenthetical expression. If the distance or length of roadway over which the tram was to be man-handled was regarded as a factor in the size, then the size would be definite. In most mines and collieries this distance was fixed, in room-and-pillar work, by the length of the rooms and the distances between cut-throughs on entries, since this was the distance through which cars had generally to be man-handled; and he supposed that in longwall work the advancing faces would be cut off at stated intervals by what he believed were known as "cross-gates." If the distance over which the tram was to be hauled from the point of delivery at the main haul were taken as the factor, the size of the car would then, upon the preceding hypothesis, be determinable only by the greatest length of haul.

Again, it was stated that "in thin seams a predetermined minimum height and width of gate-road is set up by the size of the tram." If this was the case, it appeared to him that this was a method practically reversing that generally adopted to determine the size of the tram. If he understood the expression correctly, the author inferred that the size of the tram was fixed or determined before the seam was developed to such an extent as to reveal the conditions under which the tram was to be used. In such a case the dimensions of the tram were not made to conform to the natural conditions—in other words, the natural conditions were made to conform to the arbitrary conditions. Such a method was injudicious and unbusinesslike. It was easier and less expensive to make arbitrary conditions conform to natural ones than the reverse. The height of the seam and the nature of the contiguous strata should, within prescribed limits in all seams, determine the cross-section of all roadways, and the size of the roadway should determine the size of the tram.

The calculations with reference to the facility with which trams of various weights and coefficients of friction could be man-handled were a very instructive feature of the paper, and, in determining the size of the vehicles used in the transportation of coal underground, this was a factor to which adequate consideration had not been given by operators; in fact, the labour involved in man-handling trams was the last factor taken into consideration in the United States, although it was perhaps one of the most vital features in the production of output, as

he had already explained. Conservatism had become an industrial slogan in the United States, and yet here was one of the most important factors in the conservation of human energy that was practically ignored. Man-handling in small seams could not be eliminated, but the adoption of a system of exploitation that would materially reduce the grades, either in the handling of loads or empties, or, in case this was not feasible, the installation of mechanical means as an auxiliary power, would generally reduce so unwarrantable an expenditure of energy, and conserve the waste for application to an increased output.

With respect to the diameter of wheels on a minimum-sized tram, he could not agree with the author that this should be a small diameter, for the reason that wheels of small diameter, either revolving alone or in conjunction with the axle, would make a greater number of revolutions in passing over a specified length of track than those of larger diameters. For example, a wheel 8 inches in diameter would have to revolve $1\frac{3}{4}$ times to cover the same space as a 14-inch wheel would cover in 1 revolution. Assuming that both wheels covered the same ground in the same time, it was evident that the small wheel would have to travel $1\frac{3}{4}$ times as fast as the larger. Since friction varied as the squares of the respective velocities, the small wheel would produce 3·06 times the friction of the larger, less the small increase that might be due to the increased weight of wheel. In addition, the small-diameter wheel would bring the base of the car-boxing close to the track-bed, and any obstruction of moderate size would militate against the free movement of the car.

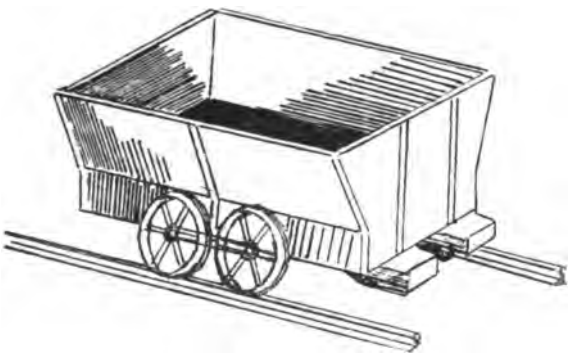


FIG. 1.—PERSPECTIVE.

It seemed to him that in standardizing cars the adoption of a standard size and construction of wheels would be one of the

first points to demand consideration. For small-capacity trams these might be lighter than in the case of those of larger capacity, and the bearings might be of simpler construction, as suggested by the author. A sketch of such wheels, with their assembling in

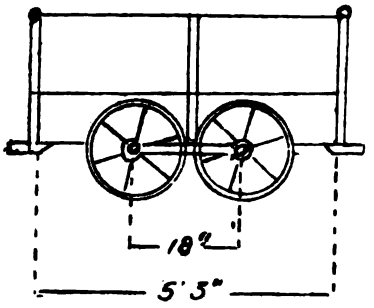



FIG. 2.—SIDE ELEVATION.

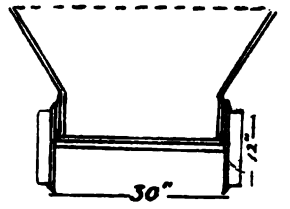



FIG. 3.—CROSS-SECTION.

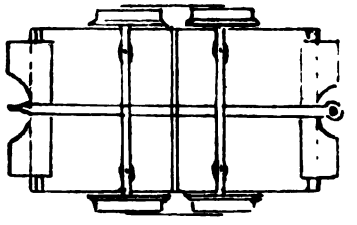


FIG. 4.—WHEEL-BASE AND GENERAL PLAN.

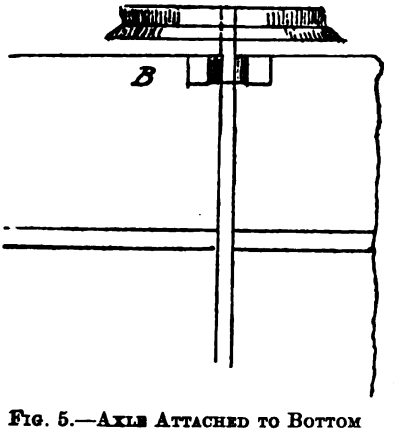



FIG. 5.—AXLE ATTACHED TO BOTTOM OF CAR BY JOURNAL BEARING.

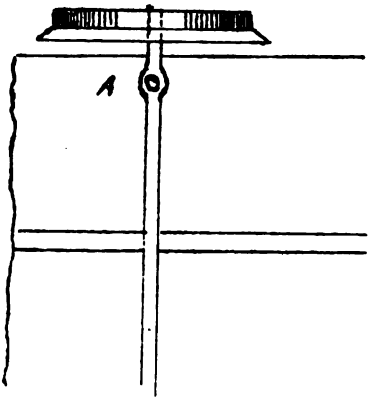



FIG. 6.—AXLE ATTACHED TO BOTTOM OF CAR BY BOLT.

the truck and their bearings for a car of 10 cwt. capacity, was shown in Figs. 1 to 6, which were not drawn to scale.

In his scale of standard trams Mr. Gibson had given dimensions that led him (Mr. Parfitt) to infer that the framework was based upon a rectangular parallelogram or a parallelopipedon,

or that the box of the car had its opposite sides parallel and perpendicular to the adjacent sides throughout their entire extent, whilst the variations in size were formed by a proportional extension of the length, width, and height. Variations of this form, in which the same capacity or a larger one might be secured by changing only one or two of the dimensions, might be desirable, and for this purpose he submitted sketches (Figs. 7 to 10) illustrative of several forms.

Mr. Gibson had clearly demonstrated the pecuniary advantages derived from the use of large trams or cars, both as to the initial cost of the equipment and the reduced expense inci-

Fig. 7.

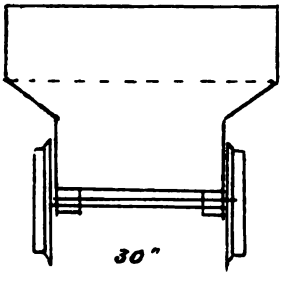
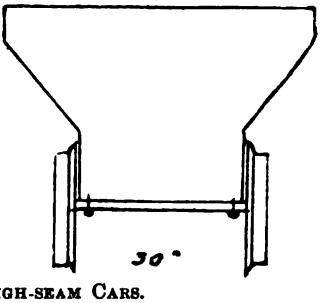



Fig 8.




Figs. 7 and 8.—High-seam Cars.

Fig. 9.

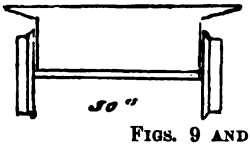
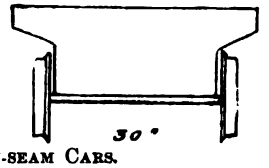



Fig. 10.




Figs. 9 and 10.—Low-seam Cars.

dent to the upkeep of the stock and track when once the latter was constructed to suit the size and capacity of the former. It seemed that the best system of haulage for the collieries of Great Britain was endless rope, as he was informed that most of the seams were gaseous, and also that most of the coals were more or less of an inflammable character, conditions which, naturally, prohibited the installation of electric haulage, although they might be adapted to haulage by compressed air. One portion of Mr. Gibson's statement relative to this subject did not appear comprehensible to the writer. He had stated that "if small trams must be used at the faces, and the road does not permit of the installation of endless-rope or such like

haulage, it follows that the best policy would be to use small trams near the faces and very large trams out-bye." He (Mr. Parfitt) understood from this that in such a case the coal would have to be transferred from the smaller to the larger trams for final haulage to the shaft-bottom. It appeared to him that this would result in a decided increase in the surface cost of the coal, and would, as the author suggested, be a strong argument in favour of standardization. Such a system, however, appeared to be impracticable.

Mr. Gibson's remarks upon the subject of tracks were pertinent and valuable, and should receive such consideration as would secure their adoption. The same conditions as to length of rails and as to the construction of track within a specified distance from the working-faces were as prominent in the majority of mines in the United States as they were in Great Britain; and the loss of time due to the one and the number of wrecks and consequent loss of time and labour incident to the other were factors that contributed largely to reduce the output and increase the cost. In the United States the rails used were generally of the " T " type, those for rooms and lateral entries being lighter in weight per unit of length than those for main haulage. He had seen, however, a rail that was more convenient for use in rooms than those mentioned. It was known as a " strap " rail, and measured about ½ inch thick by 2 inches in width and 15 to 18 feet in length. Such a rail was laid by driving it edgewise into a notched tie, so that when the rail was in position the thickness took the place of the ball of the " T " type. Such a rail could be used without the aid of spikes or nails; it was adapted to a straight or crooked road, presented a narrow friction surface, and was as enduring as the less pliable and more cumbersome " T " rail.

He had found, by comparing the length and width of car-boxings with the gauge of road and the length of truck (between centres of wheel axles) in well-balanced cars, that they bore a certain definite relation to each other, according to the following rule:—The length of the boxing was to the width (inside measurements in both) as the gauge of the track was to the length of the wheel-base (measured between centres of axles).

In standardizing cars, the gauge of the track, the wheel-

base, and the diameters of the wheels were three factors that would require little if any modification in making changes in the car capacity. Mr. Gibson suggested 24 inches as the standard gauge, and the illustrations that he had given would justify this size under surface conditions; but he (Mr. Parfitt) was inclined to the opinion that underground conditions might conduce to a change in this standard. For example, if the bottom or floor were soft, a narrow-gauge track such as was suggested would exert more pressure over a given area than one of a larger gauge would with the same load, as the weight was more concentrated, and the repairs to the track would be correspondingly greater. The size of track or wheel-base would necessarily have to be such as to enable the cars to pass easily round curves, and switches should be of the size required for the system of mining employed and the physical conditions of the seam. A wheel-base constructed upon the rule given, in which the gauge was 1·75 times the distance between the wheel centres, would, he thought, meet the conditions, as cars of 2 tons capacity constructed upon this plan would round curves and switches of a small radius. With regard to wheels, they should not be less than 12 inches in diameter, and should be of uniform shape. The gauge and the wheel-base having been standardized, the boxing or body of the car could be constructed to suit these dimensions, or such modifications in form could be made at a comparatively small expense as compared with modifications in the factors given, if the boxing were constructed of wood, as would best suit existing conditions. With the assumed minimum diameters of wheels, the minimum gauge should not be less than 30 inches.

Mr. John Gibson (Kilmarnock) wrote that his main purpose in preparing the paper was to show the great efficiency and economy that would follow the adoption of standardized trams, or even the gauge. To show in detail every step of reasoning would have required a paper of very great length. As mining engineers were usually very fully occupied in ordinary practice, he had thought that a brief paper would be more widely read than one full of details such as would possibly be familiar (and therefore tiresome) to the majority of the members. He preferred the risk of being obscure rather than prolix, although any obscurity was to be regretted. Brevity also had this great advantage—that

criticism was kept more closely focussed on the chief proposition and less dissipated on interesting though inessential details and side issues.

Several gentlemen had questioned the statement that "in thin seams a predetermined minimum height and width of gate-road is set up by the size of the tram." This dictum permitted of very easy explanation. It was stated in the paper that "a man has no great difficulty in travelling in a road having a minimum height of 3 feet above the rails and a width of 3 feet between the narrowest timbers," and that statement had not been questioned by anyone. It followed that, if the tram in use could not pass through any part of a gate-road of such dimensions, the gate-road must be increased in size. Therefore, the tram predetermined the minimum height and the width of the gate-roads. He would illustrate his remarks by a 22-inch seam, in which 2½ feet of ripping, 6 feet wide, was taken down, so that the gate-road then measured 4 feet 4 inches in height by 6 feet in width. Even with a good pavement, the height 30 yards back from the face would not be more than 3½ feet. If a 4-inch bar were used, the height would then be 3 feet 2 inches; and the sleeper and rails would again reduce this to 2 feet 10 inches above the rails. If the bar sagged 3 inches, the total available height would then be 2 feet 7 inches. Even if a tram of minimum size were used in such a road, the drawer would be in danger of losing fingers, of smashing out the bars, or at least of jamming his full tram between the rails and the roof. All these conditions were very familiar to those who worked very thin seams. The same process went on in connexion with the sides: the packs were pushed out and toppled over; the cost of repairs was high, and stowage was usually scarce; therefore a road 3 feet wide between the narrowest timbers sufficed if the tram could pass, and this width was economical. If the tram were large, it was evident that gate-roads of greater height and width must be maintained and repaired, or cross-gates must be more frequent. This extra cost must be charged against the tram.

Another assertion that had received adverse criticism was that "wheels of small diameter and simple bearings are suitable for small trams." Mr. Lupton and Mr. Parfitt seemed to be of opinion that friction must be kept down to the lowest practicable limits in trams of all sizes. Let them take, as an example, three

trams weighing 3, 4, and 6 cwts. respectively, and assume that with simple bearings the friction equalled $\frac{1}{60}$. Assuming that, by the provision of roller or other bearings, the friction was reduced to $\frac{1}{120}$, and that each bearing added 14 pounds to the weight, the weights would then be $3\frac{1}{2}$, $4\frac{1}{2}$, and $6\frac{1}{2}$ cwts. respectively. The limits of inclination would be as follows:—

(1) TRAMS WITH SIMPLE BEARINGS.

| Weight. Cwts. | Friction. | Limit of Inclination. |
|---|---|---|
| 3 | $\frac{1}{60}$ | 1 in 6 (approximately). |
| 4 | do. | 1 ,, $8\frac{3}{4}$ ,, |
| 6 | do. | 1 ,, 14 ,, |

(2) TRAMS WITH ROLLER-BEARINGS.

| Weight. Cwts. | Friction. | Limit of Inclination. |
|---|---|---|
| $3\frac{1}{2}$ | $\frac{1}{120}$ | 1 in 7 (approximately). |
| $4\frac{1}{2}$ | do. | 1 ,, 9 ,, |
| $6\frac{1}{2}$ | do. | 1 ,, 13·6 ,, |

The following deduction was quite clear from the foregoing figures:—

(1) With a 3-cwt. tram, it was wrong to use roller-bearings, or anything else in its construction, however useful, which added 56 pounds to the weight.

(2) With 4-cwt. trams an inclination of 1 in $8\frac{3}{4}$ was the dividing-line; steeper roads suited the lighter weight. Less steep roads gave the advantage to the tram with the lower friction.

(3) With trams weighing 6 cwts., the dividing-line was at 1 in $13\frac{3}{4}$; therefore in almost every case the roller-bearing had the advantage. Even easy gradients demanded some form of self-acting incline, and of course the low coefficient of friction made these practicable, whereas with ordinary bearings they would not be so.

He regretted his inability to agree with Mr. James Ashworth's opinion that detailed plans of the proposed standard trams should have been included in the paper. If he (Mr. Gibson) succeeded in proving to the satisfaction of the members the great benefits to be derived from standardization, he would be quite content to leave the matter of construction to settle itself. He was not pledged to nor prejudiced in favour of any form. In the same way he agreed with Mr. H. F. Bulman that nine different sizes were not required. By proposing that number he (Mr. Gibson) hoped to gain wider approbation for the general proposition. After

standardization had been adopted, the sizes least in demand would gradually fall into desuetude.

Mr. Ashworth had stated that the "Secretary of State could occupy his time more usefully than in considering the question of the standardization of the gauges of rails." He (Mr. Gibson) quite agreed with that statement. Mr. Ashworth's sentence, however, was based, he thought, on a misunderstanding of English constitutional practice, which worked in this way:—Supposing that the reform in question were in force, and that a coal-owner wished to deviate from the standard gauge for some particular reasons, he would then apply to the Secretary of State for exemption, which would be decided by his expert advisers. The Secretary of State, however, was responsible to Parliament for the decision of his advisers. Thus, if A could show that exemption was refused to him, whereas B, under the same conditions obtained exemption, a bad state of affairs would exist; but the responsibility to Parliament of the Secretary of State made such an eventuality practically impossible.

Mr. Ashworth had expressed the opinion that the question of ventilation had not received sufficient attention in the paper. In regard to this point, it might be noted that the Coal Mines Act (1) set up a standard of ventilation by requiring a certain percentage of oxygen, and by fixing a maximum for the percentage of carbon dioxide that might be present in the mine air; and (2) the Inspector being armed with certain powers might require airways to be maintained of reasonable dimensions, as also travelling and haulage-roads.

The question at issue was not regarding roads such as these, but gate-roads which from their commencement to their abandonment might not last more than three months. They were not primarily intended for ventilation, but were usually kept clear by leakage. It followed that the smaller they were in cross-section, the higher must be the velocity of the air-current, and, of course, the better for the ventilation of the road.

Mr. Kilpatrick had raised the question of the wisdom of doing anything which interfered with "natural and individual predilection." As this was interfered with in every law—with, in many cases, excellent results—it seemed that Mr. Kilpatrick feared an imaginary danger. Not only so, but custom itself had established laws which could not conveniently be broken. In the

case of ordinary clothing, anyone might design for his own particular use a garb of original texture, colour, and form, but it would probably prove less useful and convenient than clothing made in the ordinary way, and more costly. Of what advantage was " natural predilection " in such a case? In the same way with trams, everyone at present designed his own—its construction, form, and size—and the purpose of the paper was to show that this procedure was less useful and convenient and more costly than the logical method—just as in the case of clothing.

Mr. Kilpatrick had questioned the accuracy of the statement that a healthy man could for a period of 2½ minutes perform work at the rate of 0·24 horsepower. He (Mr. Gibson) had hoped to take tests of men and boys on a typical tram-road and present the results to the members, but regretted that lack of time had not permitted him to do so. In any case, the statement was made in the course of an argument to prove that in small trams it was more important to keep down weight than to keep down friction. Supposing that it was found that the output of a man was 0·12 horsepower instead of 0·24, then it strengthened (not weakened) the argument. Indeed, he had chosen the maximum figure for the purpose of proving his contention beyond question.

Mr. Parfitt's interesting criticism showed the trend of opinion in America, and gave many valuable hints with regard to construction. The sketches that he had so kindly submitted brought out clearly the lines on which American mining engineers were proceeding. With respect to nomenclature, it was interesting to note that the difficulties arising from mixed nationalities and languages had perforce brought about the standardization of trade names. Mr. John Watson in his remarks on the same subject had brought out clearly the difficulties with which engineers had to contend in this country.

Mr. Myles Brown's contribution to the discussion was notable, in that he sketched out a mode of procedure for testing the standardization proposals and for bringing them to fruition.

He respectfully appealed to the Institute not to throw aside lightly without close scrutiny the proposal for the standardization of trams, but to devote all the Institute's talents, influence, and prestige to the task of carrying out the reform if it should be considered practicable and beneficial.

## DISCUSSION OF MR. A. S. BLATCHFORD'S PAPER ON "THE INFLUENCE OF INCOMBUSTIBLE SUBSTANCES ON COAL-DUST EXPLOSIONS."*

Mr. James Ashworth (Vancouver, British Columbia) wrote that the paper was certainly interesting from the theoretical point of view, but to the man who had to look after the practical safeguarding of colliery operations the absence of any warning of the invariable presence of methane was very noticeable.

It had been stated, as the result of experiments, that in cases where certain incombustible substances were present in the air, they would arrest the flame of an explosion when the mixture of air and methane was in its most dangerous condition. If such an experimental conclusion were correct, the arrestment must, in the opinion of the writer, take place at, or very close to, the point of origin of the explosion.

If an incombustible substance was to be effective in controlling the progress of an explosion in a coal-mine, it must necessarily be intimately mixed with the air before the flame reached any particular point. In order to postulate such a condition in a coal-mine, the theory as to the presence of a pioneering cloud of dust in advance of an explosion flame must be accepted. A great many people believed and positively asserted that a pioneering cloud was always a factor, but the writer had persistently taken the opposite view, namely, that after the initiatory stage a pioneering cloud in front of the flame was an impossibility, excepting only when the speed of the sound wave was greater than the speed of the flame. Even then, the term "pioneering" was not correct, as the flame was passing through the cloud continuously, and was not actually driving the dust in front of it. If the cloud of dust were driven forward by the flame, the flame would be smothered o ; through excess of dust and want of oxygen.

All experiments on the quenching of a coal-dust flame by incombustible dust had been made with mechanical mixtures of the two dusts, and not with the dusts as they were found in collieries, where the different dusts were in layers, with the finest and most dangerous fresh dust already floating in the air.

Air under pressure was a totally different flame-carrier from

* *Trans. Inst. M. E.*, 1916, vol. li., page 369.

air at normal air-pressure, and here again was a missing factor in experiments made in galleries on the surface.

With reference to the liberation of carbon dioxide from a quench, it was to be remembered that the gas under those conditions was hot, and therefore not as effective as when cold; consequently steam gave better results when liberated from the quench than did carbon dioxide.

With respect to the controversies that were continually arising in connexion with coal-dust and flame-quenching, he (Mr. Ashworth) would like to see some notice taken of Mr. W. A. Douglas Rudge's experiments and conclusions on the thermo-electrical possibilities of an explosion and its initiation.*

Mr. A. S. Blatchford (Armstrong College, Newcastle-upon-Tyne) wrote that, strictly speaking, a reply to the points raised by Mr. Ashworth was not necessary.

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## MEMOIR OF THE LATE GEORGE MAY.

By CHARLES L. DOBSON.

George May was a native of the County of Durham, having been born at Bishop Auckland on February 12th, 1839. His father, George May, was a timber merchant in business in that town, his mother being a sister of James Thompson, late of Hurworth-on-Tees.

Mr. May was educated at the Grammar School, Bishop Auckland, and at Hartforth School, near Richmond, Yorkshire. He, even in these early days, showed that infinite capacity for taking pains so characteristic of him in later life, for many of his school-books (still extant), shown to the writer some few years ago, are models of neatness, and give evidence of very careful work.

* "On the Electrification Produced during the Raising of a Cloud of Dust," *Proc. Royal Society*, 1914, series A, vol. xc., page 256; see also discussion on the writer's paper on "The Killingworth Colliery (New South Wales) Explosion," *Trans. Inst. M.E.*, 1915, vol. xlix., pages 99-108.

He began to serve his apprenticeship in the year 1856 at the Hetton Collieries, under the late John Wales, who was at that time viewer. Mr. Wales was succeeded after his death in 1859 by the late John Daglish, under whom Mr. May completed his apprenticeship, and by whom he was appointed manager of Elemore Colliery.

In 1863 Sir Lindsay Wood, Bart., took over the charge of the Hetton Collieries on the retirement of Mr. Daglish in that year, thereby originating a close professional connexion of 45 years' standing. In the same year Mr. May was appointed by Sir Lindsay to the position of resident viewer to the North Hetton Collieries, and this post was held by him until his appointment by Sir Lindsay in 1872 to the charge of the Harton Collieries.

Whilst at North Hetton Mr. May married Fannie, daughter of the late Joseph Bourne, of Benton, Northumberland, and of his wife Sarah, daughter of Robert Nicholson, of Bewick Hill, in the same county. The Bournes were descendants of Henry Bourne, the historian of Newcastle (1694-1733), and old records show that the family were tenants on the estates of the Dukes of Northumberland 300 years ago. Joseph Bourne was a brother of John Bourne, engineer to the North-Eastern Railway Company (Northern Division) for a long period of years; whilst the Nicholsons were related to the Grace and Lambert families, well known in Newcastle and district. It is of interest to note that by this connexion Mrs. May was a cousin of Dr. W. G. Grace, the "Grand Old Man" of cricket.

Mr. May began his long connexion with the large and important Harton Collieries at the early age of 33 (a connexion which lasted for 35 years), the group at that time comprising the Harton, St. Hilda, and Boldon Collieries. The old Brandling drops in South Shields formed part of the Harton Company's property, these being connected by a wagonway with St. Hilda Colliery. During the greater part of Mr. May's connexion with the collieries, box or chaldron wagons, drawn by horses, conveyed the coal between the colliery and these staithes, the wagonway crossing on the road level several of the streets of South Shields. One of the last improvements taken in hand by Mr. May was in connexion with this wagonway, a tunnel being substituted for the level crossing over one of the busiest and most

important streets, and electric locomotives substituted for horses with great success.

In the early years of his management, St. Hilda Colliery was entirely remodelled, a new winding-engine was erected, and the shaft winding arrangements modernised by the large four-decked cages introduced, with other essential improvements and alterations. The heapstead and screening arrangements were extended, and a ventilating fan of the Guibal type (50 feet in diameter) was installed in place of the old furnace. The arrangements generally of this old-established colliery, sunk by the Brandling family in 1822, were brought up to date.

Boldon Colliery was comparatively new when Mr. May took up his position as agent, but under his management the surface arrangements were laid out in a spacious manner. This colliery was for many years one of the model collieries of the Durham coalfield, and visitors from abroad or from other districts were frequently directed to Boldon as a representative type of a modern well-equipped colliery.

At Harton Colliery the improvements carried out during Mr. May's term of management comprised extensions of the screening plant and a rearrangement of the heapstead; whilst his foresight, which was one of his strongest characteristics, led him to recommend the owners to adopt electricity as a motive power, in the days when this form of power, so far as its practical application on a large scale to collieries was concerned, was in its infancy. Before his retirement in 1907, orders were placed for an electric winder to replace the old vertical engine, which had been working for upwards of 50 years; and for a Sulzer pump to be erected at the shaft-bottom, in substitution of the old beam pump which had been installed at the time when the colliery was sunk. Mr. May did not, however, see this plant in operation, as on his retirement in October, 1907, it had not been delivered.

In 1891 the Harton Company acquired the property and undertaking of The Whitburn Coal Company, Limited, comprising Whitburn Colliery, the Marsden Quarries and Limeworks, and the railway connecting the colliery with the North-Eastern Railway line at South Shields. Under Mr. May's supervision Whitburn Colliery was transformed from a pit having only a small output into a large and successful colliery, the change necessitating, *inter alia*, the erection of a large

winding-engine, the installation of a Walker fan, and the enlargement of the heapstead and screening arrangements requisite for dealing with the increased output.

The site of the Tyne Plate Glass Works, South Shields, with the quay having a river frontage, and the railway connecting the works and the Whitburn Colliery line, were purchased by the Harton Company in 1892. A new wharf was laid down on the river front, and this site was eventually converted into an up-to-date coal-shipping staithe, having a river frontage of 700 feet and direct railway communication with the St. Hilda and Whitburn collieries.

During Mr. May's management of these collieries a lease was obtained of the land required for the formation of a railway to connect Harton Colliery with the company's shipping staithes, and this railway is now in use.

During the 35 years that Mr. May held the position of agent to the Harton Coal Company, he lived at Simonside Hall, near Tyne Dock. He took a great interest in farming, and the large estates of the company were efficiently farmed under his supervision.

In his earlier days at Harton he occasionally took mining students under his charge, and several men who have since become eminent in the profession served an apprenticeship with him.

Mr. May for a short time was a member of the South Shields Town Council and the Durham County Council, but public life of this kind made no appeal to him, and he very soon severed his connexion with these bodies.

More than once he was urged to allow his name to be put forward for a Commission as a Borough and County magistrate, and although appointed a member of the South Shields Bench, he never took his seat.

He was very keenly interested in The North of England Institute of Mining and Mechanical Engineers, and was at the time of his death one of the oldest members, his election dating back to 1862. When President of the Institute (1896-1898) his Presidential Address had special reference to the importance of improvement in the education and methods of training of the colliery mechanical engineer, a subject in which he was deeply interested; and the legacy which he left to the Institute

for the award of scholarships is evidence of the depth of his interest in educational matters, especially with reference to the scientific development of coal-mining. Mr. May was well known for his generosity, every genuine appeal receiving his liberal support.

Mr. May acted as chairman of the Haulage Committee formed by the Institute in connexion with the model coal-mine which was so prominent a feature of the Jubilee Exhibition held at Newcastle-upon-Tyne in 1887. He also represented the Institute for some years as a director of the Institute and Coal Trade Chambers, Limited, Newcastle-upon-Tyne.

He was active in the work of the Durham Coal Owners Association, being a member of the Conciliation Board and Joint Committee, and was usually appointed to any committee of importance during his long connexion with the Association. For many years he acted as one of the examiners of candidates for colliery manager's certificates, a duty in which he took much interest. Candidates who appeared before him for *viva-voce* examination were assured of a sympathetic and reassuring hearing. During his occupancy of the Presidential chair of the Institute, he acted as the external examiner of students desirous of taking the B.Sc. Degree in Mining at the Armstrong College, Newcastle-upon-Tyne.

In 1892 Mr. May was appointed a director of the Bearpark Coal & Coke Company, Limited, and by virtue of his technical knowledge he assisted his colleagues on the board in an advisory capacity up to the time of his death.

On retiring from the position of agent to the Harton Coal Company, he was appointed a director of the company, which position he likewise filled until his death.

On his retirement he took up residence at Clervaux Castle, near Croft. For some time previously his sight had caused him much trouble. Gifted, however, with a wonderful memory, he was able to remember facts read and to follow plans explained to him with remarkable ability, and, notwithstanding the severe blow which his loss of sight involved, his remaining years were cheerful and happy.

Mr. May on his retirement received from the officials and staff of the Harton Collieries a presentation of plate, this occasion affording an opportunity to his staff of showing their regard and

esteem. He was very much liked by such of the older generation of workmen as could remember his early days with the Harton Company, and he always enjoyed talking over those early days with them. He was a great lover of animals—horses in particular—and at Clervaux Castle indulged in his hobby by the breeding of Shetland ponies.

He soon became well known in the district of Croft, and was very popular with his neighbours, although he was a man who strongly disliked publicity in any form. Amongst his own circle of friends he was very much liked and esteemed. Perhaps he was seen at his best when fulfilling the duties of host, in which capacity he acted in a delightful and hospitable manner. Being gifted, as already mentioned, with a good memory, he would delight, to a sympathetic listener, in telling incidents of his early life and of old mining days.

He was a member of the Horticultural Society, of the Northern Antiquarian Society, and of one or two farming associations, and took much interest in the work of these several societies.

Mr. May died at Clervaux Castle on June 18th, 1915, and was buried in Croft Churchyard, where also lies interred his wife, who predeceased him in 1907. His two daughters, Mrs. A. Paget Steavenson, of Hurworth-on-Tees, and Mrs. Scott, of Riding Mill, survive him.

A photograph of the deceased gentleman (Plate VI.) is attached to this brief memoir.

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Prof. Henry Louis proposed and Mr. E. Seymour Wood seconded a vote of thanks to Mr. Dobson for his interesting Memoir.

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# THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS.

GENERAL MEETING,
HELD AT THE DANUM HOTEL, DONCASTER, MAY 27TH, 1916.

MR. CHARLES CHETWYND ELLISON, PRESIDENT, IN THE CHAIR.

The Minutes of the previous meeting were read and confirmed.

The following new members were elected:—

MEMBER—

Mr. OWEN WALTERS, Dundee Coal Company, Limited, Club Arcade, Durban, Natal, South Africa.

ASSOCIATE MEMBERS—

Mr. CHRISTOPHER BARBER, 60, Harcourt Road, Sheffield.

Mr. EDWARD ALLAN IRONSIDE, 40, Mincing Lane, London, E.C.

Prof. W. G. FEARNSIDES gave an abstract of the following paper on "Some Effects of Earth-movement on the Coal-Measures of the Sheffield District," etc.:—

# SOME EFFECTS OF EARTH-MOVEMENT ON THE COAL-MEASURES OF THE SHEFFIELD DISTRICT (SOUTH YORKSHIRE AND THE NEIGHBOURING PARTS OF WEST YORKSHIRE, DERBYSHIRE, AND NOTTINGHAMSHIRE).—Part II.

By Prof. WILLIAM GEORGE FEARNSIDES, M.A.,
Sorby Professor of Geology in the University of Sheffield.

## IV.—Post-Carboniferous and Pre-Permian Movements.

Having in the first part of this paper* passed in review the effects wrought upon the Coal-Measures while yet they were flat-lying as sheets of sediment continuous over an area at least as great as the twelve northernmost counties of England, the writer will now consider the movements which brought about the partition of the area and gave to the North Midland district its individuality as a separate coalfield. In the formation of this particular coalfield, earth-movements of several ages subsequent to the Carboniferous have played a part, and it will be the writer's task in the present portion of the paper to elucidate the effects which belong to the post-Carboniferous and pre-Permian Period, and to disentangle them from those of later date. A comparison of the geometry of the folded surface of one of the more important horizons in the Coal-Measures with that of the surface of unconformity which divides the Permian from the Carboniferous rocks in South Yorkshire, Derbyshire, and Nottinghamshire, is the method by which he will proceed.

### (1) *Opinions of Authorities.*

In endeavouring to ascertain what has been accomplished in this direction, one naturally turns to the publications of H.M. Geological Survey. In the chapter on earth-movements in the District Memoir *On the Geology of the Yorkshire Coalfield*, by A. H. Green, R. Russell (and others),† we find that the view

* *Trans. Inst. M. E.*, 1915, vol. l., page 573.

† H.M.G.S. District Memoir *On the Geology of the Yorkshire Coalfield*, by A. H. Green, R. Russell (and others), chapter iii., pages 487 *et seq.*

adopted is that the earth-movements which broke up the Coal-Measures of the North of England into separate coalfields took place in two stages, between which the whole period of the Permian is supposed to have elapsed. Green and his colleagues had recognized that in nearly all our coalfields the dip of the measures is generally towards the middle of the field. Their day was before the time when Suess, Heim, and Lapworth, had made their studies of alpine mountain structures, and there was none to tell them that basin structures generally develop between the minor swells and cross-folds which lie in front of or behind the great complexes of earth-wrinkles, overfolds, thrust-planes, faults, and contortions which belong to great mountain ranges, and they therefore had to find an explanation for them based on such premises as they knew.

The explanation which Green adopted was much as follows:—At the close of the Coal-Measure period the North of England was subjected to lateral pressure from the south, and parts of the country rose in ridges which he distinguishes by Hull's name of the "Pendle anticlines." These ranged "east and west or E.N.E. and W.S.W." One of them "from Clitheroe north of Pendle Hill past Skipton towards Harrogate" forms the northern boundary of the Yorkshire field. Another, "very largely hidden beneath the new Red Sandstone, runs in an east-and-west direction to the south of Nottingham and terminates the [North Midland] coalfield on the south."* Subsequent to such uplift the country was planated (or levelled) by denudation. "As each arch was squeezed up, denudation took slice after slice off its crest, and by this means along the central line of each saddle the lower beds were stripped of the covering beneath which they were originally buried and now show themselves at the surface. Those portions of the higher beds which were sunk into troughs escaped in large measure and survive."† After this cycle of denudation, the area is supposed to have sunk down beneath the waters of the Magnesian Limestone sea and to have received successive sheets of Permian sediments. At the close of the Permian Period it again emerged, and the Pennine system of folding is supposed to have been impressed upon it. Concerning these Pennine folds we are told that "the Pennine anticlines range approximately north and south; along

* *Loc. cit.*, page 488.

† *Ibid.*, page 487.

[which] line the rocks are really folded over many times in succession, but the general result has been to produce a broad flat arch running from Derbyshire northwards into Scotland."*

Why precisely Green took the view that the Pennine system of folding is later than the Permian we are not told. Possibly he took it direct from Hull, who seems to have founded it on observations† made as to the relationship between the Trias and certain red rocks which he mistook for Permian along the line of country traversed by the great faults known as the "anticlinal" and the "Red Rock" faults between Leek in North Staffordshire and Colne in Lancashire along the west side of the Pennines, which red rocks are now known as the "Keele Series," and belong to the period of the Upper Coal-Measures. In any case, the view has not been allowed to stand unchallenged.

Gibson, on whom in recent years the mantle of Green seems to have fallen, and who has been responsible for a great deal of the re-mapping both of the Nottingham and the Derby portion of this coalfield, and of the West Pennine districts, has joined issue very directly upon this question.

Dealing with the structural features of the area which has become known as "the Concealed Coalfield of Yorkshire and Nottinghamshire," he states that "the main structures originated and were stereotyped during the long interval which elapsed between the close of the Carboniferous and the opening of the Magnesian Limestone Period." Gibson, like Green, seems to think that two movements, each of the nature of a lateral thrust, have taken part in the formation of the coal-basins. Of the direction of these movements he says: "By far the most powerful thrust came from the east. It was accompanied, or according to some authorities it was preceded, by a secondary impulse from the south and south-east. . . . While the relative age of the movements is disputed, it is quite certain that the two sets operated and were completed before the Magnesian Limestone Period." "When at the commencement of the Limestone epoch depression and sedimentation again took place, the complicated structure and its outline had been almost completed."‡

* *Loc. cit.*, page 487.

† "Observations on the Relative Ages of the Leading Physical Features and Lines of Elevation of the Carboniferous District of Lancashire and Yorkshire," by Edward Hull, M.A., F.R.S., *Quart. Journ. Geol. Soc.*, 1868, vol. xxiv., page 331.

‡ H.M.G.S. District Memoir *On the Geology of the Concealed Coalfield of Yorkshire and Nottinghamshire*, by W. Gibson, pages 37-38.

From these excerpts taken from the Survey Memoirs on "The Geology of the Yorkshire Coalfield" (1878) and on "The Concealed Coalfield" (1913), it is evident that in the course of the last 35 years there has been a considerable change in the opinions held by geologists as to the age of the anticlines which together form the "Backbone of England." Not all the evidence comes from coalfield geology, and it by no means follows that the last word has yet been spoken upon this most fascinating of problems in the geology of the North of England. Green, perhaps, drew his inferences from observations made in the north, Gibson his from data obtained in the south Pennine country, and it may be that this difference in the *locus* as well as in the date of their geological education may be largely responsible for the differences in their points of view.

### (2) *The Preparation of a Map.*

Stimulated by Dr. Gibson's memoir, and wishing to learn at first-hand what really are the structures of the coalfield in which he was about to take up work, the present writer, when first he came to Sheffield, had intended to set about the making of a model of the district. A course of field work, with visits to collieries and inspection of colliery maps and plans, and a perusal of those chapters of Green's writings in which the districts he visited were described, soon persuaded him that the main structures of the South Yorkshire district are so broad and open that only a large-scale model can be of use, and that for general educational purposes almost all of them can be quite as well represented by means of maps.

The contour method, long familiar to water engineers, seems first to have been applied to the interpretation of borehole information by Dr. Strahan.* Its successful use by Dr. Gibson for the interpretation and reconstruction of the form of the surface of unconformity at the base of the Permian had shown its possibilities in coalfield work, and the time was therefore ripe for the extended application of the method to the study of the

* In abstract—A. Strahan, *Proc. Royal Society*, 1905, series A, vol. lxxviii., page 246; in full—Appendix to chapter i., *Professional Paper, No. 10*, Survey of India, 1908. For earlier papers presenting geological information by the method of contours, cf. M. Bertrand, "Sur la Continuité du Phénomène de Plissement dans le Bassin de Paris," *Bull. de la Societé geologique de France*, 1892, series 3, vol. xx., page 118, and fig. 3, page 128; also W. W. Watts, "Charnwood Forrest: a Buried Triassic Landscape," *Geographical Journal*, June, 1903, pages 1-14 and plate i.

coal-seams themselves. A start was made with the contours of the Top Hard Seam of coal, which, when plotted from information contained in the Sheet Memoir, Explanation of sheet 125, "On the Geology of the North Derbyshire Coalfield" and in the District Memoir "On the Geology of the Concealed Coalfield," on the same map with those of the base of the Permian, showed how frequently the direction of the strike of the Permian rocks makes a considerable angle with the strike or level line in the Coal-Measures which they overlie, and demonstrated very clearly the truth of Gibson's contention that "the Permian rocks, gently inclined, pass over the edges of the Coal-Measure anticlines and synclines without themselves being folded."

Just at that time the book of tabulated *Sections of Strata of the Coal-Measures of Yorkshire*, compiled by the Sections Committee of the Midland Institute of Mining, Civil, and Mechanical Engineers, was published, and this, with its accompanying map showing the approximate localities to which each section belongs, provided information ready to be applied to the same purpose. Accordingly a year ago a sketch-map on the topographical basis of the Midland Institute's map was produced, showing approximate underground contour-lines both for the base of the Permian formation and for the Barnsley Seam of coal, and the surface outcrops of the beds contoured were transferred from official Geological Survey maps. The map thus prepared was shown to Mr. G. Blake Walker, and through him offered for publication to the President and Council of the Institute, by whom it was referred to the Finance Committee of The Institution of Mining Engineers. By each of these authorities the practical utility of such a map to mining men was recognized, and when certain imperfections and omissions in the plotting of the pit-sites were pointed out to them, authority was given for a new map to be prepared with the information noted with as much precision as the scale of the map allowed. For the new map (Plate VII.) the black-and-white basis was prepared by Messrs. John Bartholomew & Company as long ago as October, 1915. The location of its area (25 by 25 inches, representing some 2,500 square miles of country), in its relation to the other coalfields of the North of England, is shown by the inset square on the geological key-map (Fig. 1 in the text). The area has been so chosen that, while no important working collieries have been

excluded on the north and west (Bradford, Halifax, and Leeds district), more of the Derbyshire and Nottinghamshire part of the coalfield is included than on the former map, and Sheffield is

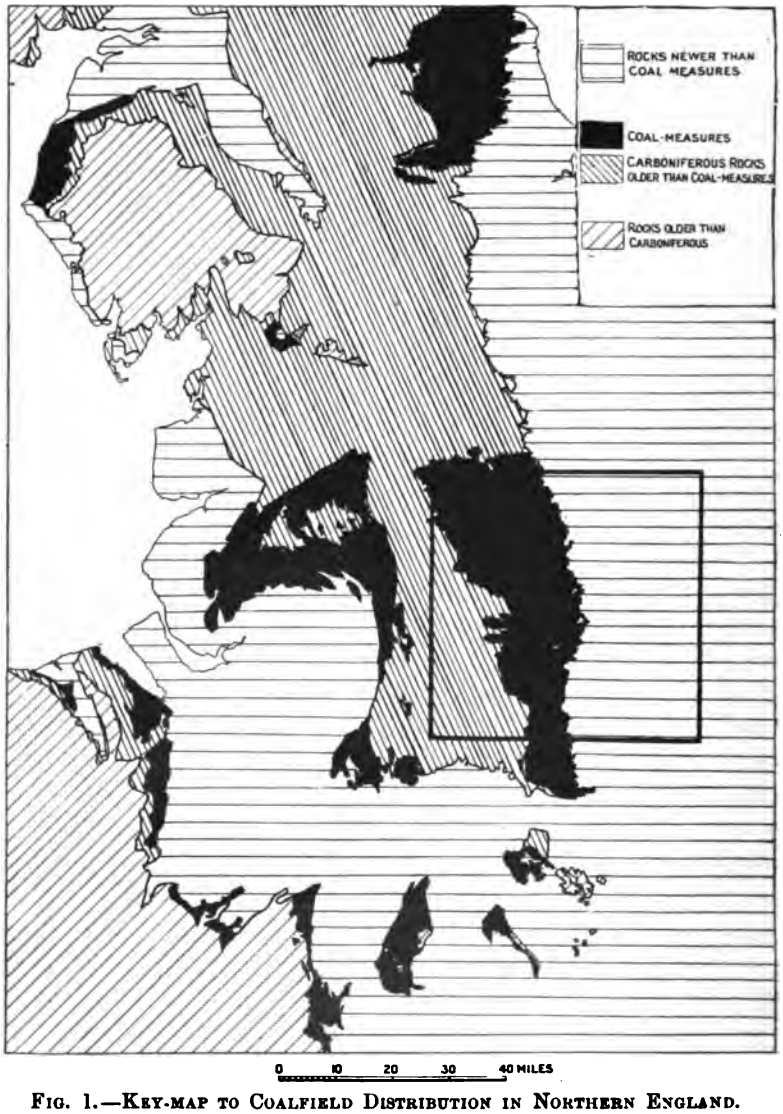

ROCKS NEWER THAN COAL MEASURES
COAL-MEASURES
CARBONIFEROUS ROCKS OLDER THAN COAL-MEASURES
ROCKS OLDER THAN CARBONIFEROUS
0 10 20 30 40 MILES

Fig. 1.—Key-map to Coalfield Distribution in Northern England.

shown more nearly in the middle of the district from which its fuel-supplies are drawn. The list of pit-sites shown was drawn up from the Home Office *List of Mines* (No. 3, York and North Midland Division) for 1913 (the latest complete year in which

coal-mining conditions can be accounted normal in this country), and all pits within the area of the map which in that year gave employment to more than 25 men underground are to be plotted.

At first it was hoped that an inspection of large-scale Ordnance maps would supply the information as to pit-sites, but the difficulty soon arose of distinguishing which of the many buildings at a large colliery represent the shafts, and which of the shafts shown on the Ordnance map of the coalfield have now become disused. Eventually it was decided that the only way of proving the shaft locations was to make a personal visit to the collieries themselves. This part of the work is being carried out, but there still remain a few pits to be visited before the map in completed form can be handed over to the printer.* Geological information as to outcrops was transferred, with one or two minor corrections, made necessary by more recent mining information, from the official maps of the Geological Survey. In addition to the lines of outcrops of (1) the base of the Permian and (2) the Barnsley Bed and its equivalents, the Gawthorpe and Warren House Seams of West Yorkshire and the Top Hard Coal of Derbyshire, the upper limit of the Permian formation where it adjoins the Trias or the recent alluvium of the lower basin of the Don has been shown, and below the Barnsley Bed lines of outcrop of the Silkstone and Blocking coals of Yorkshire and their equivalent, the Black Shale or Clod Coal of Derbyshire, and still lower that of the Halifax Hard or Gannister Coal and its equivalent the Alton Coal of Derbyshire, have also been transcribed. The horizon of this last, the lowest coal persistent across the district, and notable for its inclusions of " coal-balls " or " bullions," as well as for the marine roof which it underlies, has been plotted instead of the upper limit of the Rough Rock of the Millstone Grit Series (which the Geological Survey has adopted as the base of the Coal-Measure Series), as being a horizon which practical men can be more sure of recognizing when they meet it in shafts or in the cores from boreholes.

(3) *Geology of the Pre-Permian Surface of the Coal-Measures.*

Before discussing the contours as drawn on the map, it may be convenient to tabulate the evidence on which they are based.

* The colour-printed map (Plate VII.) is, therefore, not available for issue with the present Part of the *Transactions*. It is probable that it will be ready for distribution in October, 1916.

For each record of the depth below the surface at which the base of the Permian occurs in shafts and boreholes, is subtracted the height above sea-level at which the exploration was begun. This brings the levels for each different locality into relation with Ordnance datum, and makes the records comparable one with another. Arranged in order of the height above sea-level at which the depth to the base of the Permian is available, the list of sites is as follows:—

| Site. | Feet above or below sea-level. | Site. | Feet above or below sea-level. |
|---|---|---|---|
| *Sutton | +500 | Clipstone | −270 |
| *Teversal | +450 | *Welbeck | −275 |
| Barlborough No. 2 | +425 | Bullcroft Main | −332 |
| Southgate | +413 | Doncaster Gas Works | −339 |
| Kirkby | +356 | Farnsfield, No. 1 | −488 |
| Pleasley | +346 | Bentley | −500 |
| Southgate | +320 | Manton | −500 |
| Ledstone Luck | +230 | Rossington Main | −525 |
| Peckfield | +151 | Harworth | −600 |
| Shirebrook | +143 | Armthorpe No. 1 | −905 |
| Sherwood | +138 | ,, No. 2 | −921 |
| Whitwell | +120 | Pollington | −960 |
| Maltby Main | + 82 | Cantley | −980 |
| Langwith | + 55 | Bevercotes | −1,041 |
| Creswell | + 50 | Carlton (West Bank) | −1,071 |
| Steetley | + 41 | Hatfield Main | −1,083 |
| Warsop Main | + 22 | Selby | −1,268 |
| Fryston | − 10 | Selby Barlow | −1,289 |
| Brodsworth Main | − 61 | Thorne | −1,518 |
| Shire Oaks | − 64 | Haxey (South Car) | −1,719 |
| Askern Main | − 70 | Rawcliff (Newland Hall) | −1,730 |
| Mansfield | − 83 | South Leverton | −1,940 |
| Wallingwells | −100 | South Scarle (Collingham) | −1,985 |
| Yorkshire Main | −180 | Wressle | −2,000 |
| Byram Gardens | −230 | Reedness | |
| Rufford | −250 | Amcotts | |

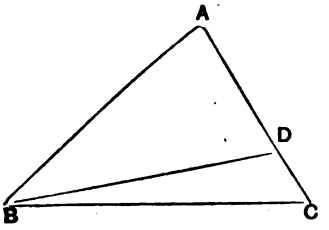
The levels given for the pits marked with an asterisk are only approximate.

If we choose as the convenient vertical interval between successive contours the arbitrary distance of 100 yards, it appears that of the pits and boreholes in this list—

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | are | above | the | contour | drawn | at | 100 | yards | above | sea-level. | |
| 10 | ,, | between | 100 | yards | above | sea-level | and | Ordnance | datum. | | |
| 11 | ,, | ,, | Ordnance | datum | and | 100 | yards | below | sea-level. | | |
| 6 | ,, | ,, | 100 | yards | below | sea-level | and | 200 | yards | below | sea-level. |
| None | ,, | ,, | 200 | ,, | ,, | ,, | ,, | 300 | ,, | ,, | ,, |
| 8 | ,, | ,, | 300 | ,, | ,, | ,, | ,, | 400 | ,, | ,, | ,, |
| 2 | ,, | ,, | 400 | ,, | ,, | ,, | ,, | 500 | ,, | ,, | ,, |
| 3 | ,, | ,, | 500 | ,, | ,, | ,, | ,, | 600 | ,, | ,, | ,, |
| 5 | ,, | below | 600 | ,, | ,, | ,, | | | | | |

In order to find the actual positions for the contour lines, the simple assumption is made that between each pair of neighbouring points at which levels are available, the rocks lie along the

straight line joining them, and that therefore the difference in height is distributed uniformly along these straight lines. If we take, then, one of the points, which may be termed $A$, the height of which is $a$ feet above or below sea-level, and consider it in its relationship to two neighbouring points $B$ and $C$, the heights of which in feet are respectively $b$ and $c$ ($b$ being some number intermediate between $a$ and $c$), the triangle $ABC$ may be constructed.




If we then divide the line $AC$ at $D$ in such a way that $AD : DC :: a-b : b-c$, and join $BD$, we obtain a line which joins two points both at the same level, and this line is assumed to be the contour at the level $b$ feet above or below sea-level. All other lines drawn parallel to $BD$ within the area of the triangle $ABC$ are also contour lines, and when by the similar treatment of all neighbouring groups of three points where spot-levels are recorded on the map, the direction of the contours has been determined, the place of those particular ones which represent integral numbers of hundreds of yards is marked off by taking their proportional intercepts along the sides of the various triangles.

By such a construction the map becomes covered with a network of triangles each of which is divided into strips by its own series of evenly-spaced average level or strike-lines. Over the southern half of the country shown on such a map, from south of the Dukeries almost up to Doncaster, all these lines of average strike for the base of the Permian keep an even north-and-south direction. In that district they are sub-parallel and very evenly spaced; they converge somewhat northwards and, without changing direction appreciably where they carry on from one triangle into its neighbour, crowd a little westwards from the east. About Doncaster and farther northwards as far as Askern there is less regularity. In the triangle formed by joining up Rossington Main, Yorkshire Main, and Bentley, the contours evidently range north-westwards. Between Bullcroft Main, Bentley, and Askern Main they must trend north-eastwards; whereas in the area northwards from Askern Main to

Ledstone Luck and eastwards as far as Pollington a direction considerably west of north is resumed. East of Doncaster, towards Selby, Goole, and Gainsborough, the regularity of contours characteristic of the southern half of the area appears to continue hardly disturbed.

So far the problem of plotting contours from determined spot-levels has been treated as one of geometry only, and the evidence gained by their construction has made it certain that the surface dealt with has geometrical properties not very different from those of a gently sloping plane, which must dip down fairly regularly in a direction some 20 degrees north of east, and undergo a change of level of some 800 to 1,000 yards in the course of 20 miles. With this geometrical construction accomplished, the next part of the process is to adapt the lines in accordance with the geological features of the superficial land-surface of the area. A consideration of the line of outcrop of the surface below the basal Permian, and of its behaviour in crossing the contours of the existing ground surface, gives useful suggestions as to how that surface where below ground may be subject to slight transverse waves. The position, the width (that is, the wave-length), and the changes in level (that is, the amplitude), of these transverse waves at the outcrop are especially useful in suggesting the place and scale of the adjustments which may be allowed in "sweetening" the run of the contours underground.

A plotting of the points where the outcrop transgresses the 300-foot surface contour gives additional information, which enables one to locate the course of the +100-yard contour at several places where no mining information is available.

By the inspection of the line of outcrop of the base of the Permian, as shown on the geological map, with these objects in view, it may be noted that—

(1) An anticline through Teversal, flanked by the pair of shallow synclines which contain the limestone outliers of Hucknall under Hulthwaite and of Hardwick Hall Park, causes some irregularities of geometry from the southern edge of the map as far as Glapwell.

(2) The limestone about Clowne and Barlborough is in a wide but shallow trough, which brings the outcrop in that district somewhat westward of its normal position.

(3) About Harthill and northwards to the Kiveton Park Fault the Permian is upraised as by an anticline, but falls back westwards on the northern (that is, the downthrow) side of the fault.

(4) Between the Kiveton Park Fault and the Don Faults the Permian lies very regularly, and is undisturbed. East of Conisborough the faults carry the limestone outcrop westwards in a trough to Hooton Roberts, where it lies at least 300 feet below its proper position, and almost 2 miles out of line.

(5) Northwards, before High Melton is reached, the effect of the Don Fault disturbance is neutralized by a gentle anticlinal swell which holds the outcrop back eastwards almost to Hickleton. Between Hooton Pagnell and South Elmsall this swell subsides into a wide trough, considerably broken along the midst of it by a number of faults which evidently increase in throw north-eastwards. East of Brodsworth the strike is north-east and south-west, and normal conditions only resume north of Wentbridge.

(6) The Pontefract outlier is not particularly out of line, but thence northwards to Micklefield, where the outcrop of the base of the Permian crosses the northern margin of the map, a succession of broad open folds causes the strike to vacillate irregularly between north and north-west.

With this evidence to guide us, and bearing in mind the geometrical property which demands that contours drawn at equal vertical intervals upon a sloping plane must appear in plan as parallel and equidistant lines, the remaining adjustments and exterpolations required to complete the contour lines across the whole area of the map have been drawn in by eye freehand.

The Barlborough syncline (2) evidently ranges south-eastwards, and by reason of its influence the pits at Warsop Main, Langwith, Creswell, and Whitwell appear almost upon the same line of Permian strike. There is at present no available evidence that this syncline extends beyond the contour of −100 yards. The Harthill anticline and the Kiveton Park Fault (3) disturb the sea-level contour in the neighbourhood of Steetley and Shire Oaks. The contours of +100 and −100 yards have been adjusted to sweep round in accordance with the bends of that contour. The depth at Manton suggests that similar irregularities may also there affect the contour of −200 yards. The trend of this disturbance is about 30 degrees south of east.

The disturbance due to the Don Faults (4) at Conisborough is the most abrupt of those that affect the Permian outcrop in this area. From the depth to Coal-Measures at Yorkshire Main one may infer that the Permian rocks have suffered a downthrow of between 150 and 300 feet as compared with their level in the country a mile or two to the south. This displacement, although considerable, is not so great as that required to bring the limestone to its position at Hooton Roberts, and there is consequently some reason to suggest that the throw of the Don Faults as they affect the Permian is decreasing as one passes eastwards away from the outcrop. A comparison of the depth to the base of the Permian at Doncaster Gas Works with that at Rossington Main and at Bentley suggests that in the neighbourhood of Doncaster the displacement has become inconsiderable, an inference which is further supported by the evidence of the group of three boreholes east of the contour −300 yards in the neighbourhood of Armthorpe and Cantley. The line of the Don Valley disturbance seems to trend somewhat east of north-east, a direction almost directly at right-angles to the main trend of the folding which affects the Permian rocks farther south.

Although the South Elmsall disturbance (5) is much less acute than that due to the Don Faults, the displacement of the contour-lines which is effected in its neighbourhood is more considerable, and their direction appears abnormal over a greater area than anywhere else on the map. From Doncaster about as far as Brodsworth the trend is west of north, but between the Brodsworth and Bullcroft district and Askern Main the contours step back north-eastwards, as if the rocks were upraised by an anticline over a distance of nearly 4 miles. This displacement is approximately twice as great as that produced by the Don Faults at Conisborough. As represented on the map, all contours east and south-east of Askern Main, down to that of −300 yards, are affected by this disturbance. The bends in the sea-level contour are justified by the depths at Brodsworth and Askern Main, and by the surface outcrops east of South Elmsall. That the −100-yard contour must bend in accordance therewith is proved by the depth at Bullcroft Main, which lies within it, and is almost on a direct north-east and south-west line between the pits at Brodsworth and Askern, where the levels

are almost 100 yards higher. The −200-yard line must lie east of Bentley, while the place of the −300-yard line is determined with some precision by the depths recorded from Armthorpe, Hatfield Main, and Pollington. Whether the whole of this disturbance is due to the broken north-east anticline which affects the surface outcrops east of Elmsall, or whether it is this anticline complicated by a transverse north-east and south-west swell through Badsworth (which seems to be required in order to account for the preservation of the outlier of Upton Beacon), is a problem that is not likely to be solved until further mining operations have provided fuller information about the district east of Askern and north of Hatfield Main.

With respect to the levels in the country between Pontefract and Selby, only the depths at Peckfield and Ledstone Luck Pits and old information provided by the Byram Gardens borehole have been made public, and the contours across most of that district can only be drawn in accordance with obscure information gained from the surface outcrops of the rocks. Depths at half-a-dozen boreholes in the Selby district and east of it even beyond the Trent are on record, and they provide some evidence which suggests that the contours in that district have changed their direction somewhat, swinging round some points further towards the north-west. The regularity with which the contours space themselves across this north-eastern district makes it improbable that there is any very violent cross-folding such as would disturb the regularity of the lie of the Permian rocks across the lower basin of the Ouse.

(4) *Geometry of the Surface of the Barnsley Seam of Coal.*

Leaving for the moment the further discussion of the form and lateral extent of the pre-Permian surface, the writer will pass to the application of similar methods for obtaining contours of the surface of a seam of coal. Among all the coal-seams in the North Midland field to which the method might be applied the Barnsley Coal of Yorkshire and its equivalent, the Top Hard Coal of Derbyshire and Nottinghamshire, has been selected as the horizon of greatest commercial importance, and concerning which the greatest amount of information is therefore available.*

* According to the Home Office *List of Mines*, not less than 85,814 men, of whom 69,034 were underground workers, in 1913 found employment at the seventy-four pits which were engaged in the exploitation of the Barnsley Coal and its equivalents in the area shown on the map (Plate VII.).

In order to remind ourselves of the general non-parallelism and disagreement in geometry between the coal-seam surfaces and that of the basal Permian, the following passage with which Mr. Lamplugh opens his chapter on the Permian, in the special memoir on the geology of the country round Nottingham, may be quoted:—

"We have laid stress [he says] on the great break or unconformity which occurs in the North Midlands between the Carboniferous rocks and the strata which cover them. The time represented by this unconformity is long, since in the interval the Carboniferous sediments were not only consolidated and uplifted, bent into folds and faulted, but were also deeply pared down by erosion, so that the Permian strata of the North of England rest indiscriminately upon all members of the older system in turn."*

The surface to which erosion pared down the Coal-Measures is the surface which, by later tilting and gentle folding, has attained the geometry previously discussed by the writer. The geometry of one bed in the measures which is "bent into folds and faulted" is the subject for the investigation now before us.

Among the forty or more coal-seams which are at present worked within the area shown upon the map, few are well recognizable as continuous over the whole area, and the Barnsley Bed of South Yorkshire, with its equivalents the Gawthorpe and Warren House Coal of West Yorkshire and the Top Hard Coal of Derbyshire and Nottinghamshire, was chosen as being the seam most persistent and most generally in course of active exploitation and development over the widest area.

After correction for the height above sea-level at which sinking or boring operations were begun, the list of working pits or boreholes from which useful information as to depths is available is as follows:—

| Pit. | Height above or below sea-level of the Barnsley Bed. | Height above or below sea-level of base of Permian. | Difference = thickness of Coal-Measures above Barnsley Bed. | Pit. | Height above or below sea-level of the Barnsley Bed. | Height above or below sea-level of base of Permian. | Difference = thickness of Coal-Measures above Barnsley Bed. |
|---|---|---|---|---|---|---|---|
| | Feet. | Feet. | Feet. | | Feet. | Feet. | Feet. |
| *Silver Hill ... | +400 | — | — | *Grassmoor ... | +220 | — | — |
| *Tibshelf ... | +400 | — | — | New Stubbin ... | +160 | — | — |
| *Alfreton ... | +375 | — | — | Barugh (Redbrook) | +160 | — | — |
| Swanwick (Old) | +352 | — | — | Low Laithes ... | +140 | — | — |
| *Blackwell ... | +350 | — | — | Handsworth ... | +124 | — | — |
| Swanwick (New) | +310 | — | — | Lofthouse ... | +90 | — | — |
| *Holmwood ... | +300 | — | — | South Normanton | +90 | — | — |

The depths given for the pits marked with an asterisk are only approximate.

* H.M.G.S. Special Explanatory Memoir *On the Geology of the Country Round Nottingham*, page 24.

| Pit. | Height above or below sea-level of the Barnsley Bed. | Height above or below sea-level of base of Permian. | Difference = thickness of Coal-Measures above Barnsley Bed |
|---|---|---|---|
| | Feet. | Feet. | Feet. |
| Old Roundwood | +83 | — | — |
| Hoyland Silkstone | +68 | — | — |
| Williamthorpe | +60 | — | — |
| Allerton Main | +50 | — | — |
| New Hucknall | +25 | — | — |
| North Gawber | +6 | — | — |
| Newmarket (Nelson) ... | −6 | — | — |
| Barrow ... | −33 | — | — |
| Wrenthorpe ... | −73 | — | — |
| Wooley ... | −88 | — | — |
| Beighton ... | −90 | — | — |
| Allerton Bywater | −99 | — | — |
| *Sutton ... | −100 | +500 | 600 |
| Elsecar Main ... | −108 | — | — |
| Langton ... | −118 | — | — |
| *Teversal ... | −130 | +450 | 580 |
| Portland ... | −137 | — | — |
| Warren House | −150 | — | — |
| Barlborough No. 2 ... | −180 | +425 | 605 |
| Bentinck ... | −220 | — | — |
| Parkhills ... | −257 | — | — |
| Fence... ... | −268 | — | — |
| Orgreave ... | −273 | — | — |
| Car House ... | −284 | — | — |
| Aston... ... | −292 | — | — |
| Barlborough No. 1 ... | −320 | — | — |
| Seymour ... | −328 | — | — |
| Norwood ... | −338 | — | — |
| Ireland ... | −343 | — | — |
| Waleswood ... | −350 | — | — |
| Whitwood ... | −350 | — | — |
| Aldwarke Main | −350 | — | — |
| Crigglestone ... | −357 | — | — |
| Cortonwood ... | −381 | — | — |
| West Riding ... | −386 | — | — |
| Wharncliffe Woodmoor ... | −394 | — | — |
| Wombwell Main | −422 | — | — |
| Roundwood ... | −426 | — | — |
| Carlton Main... | −429 | — | — |
| St. John's ... | −434 | — | — |
| West Kiveton.. | −436 | — | — |
| Tinsley Park ... | −448 | — | — |
| Oxcroft ... | −456 | — | — |
| Southgate ... | −460 | +413 | 873 |
| Wheldale ... | −466 | — | — |
| Fryston ... | −477 | −10 | 467 |
| High Hazels ... | −497 | — | — |
| Kirkby ... | −547 | +356 | 903 |
| Glapwell ... | −582 | — | — |
| Barnsley Main | −637 | — | — |
| Whitwell ... | −640 | +120 | 760 |
| Glass Houghton | −643 | — | — |
| Markham No. 1 | −701 | — | — |
| West Sharlston | −710 | — | — |
| Monk Bretton | −714 | — | — |
| Manvers Main | −764 | — | — |
| Thrybergh Hall | −772 | — | — |
| Snydale ... | −780 | — | — |
| Mitchell's Main | −796 | — | — |
| Ackton Hall ... | −819 | — | — |
| Featherstone Main | −824 | — | — |
| Treeton ... | −824 | — | — |
| New Oaks ... | −837 | — | — |
| Bolsover ... | −838 | — | — |
| Kiveton Park... | −900 | — | — |
| Palterton ... | −900 | — | — |
| Sherwood ... | −900 | +138 | 1,038 |
| Darfield Main.. | −902 | — | — |
| Wath Main ... | −962 | — | — |
| Creswell ... | −1,035 | +50 | 1,085 |
| Pleasley ... | −1,043 | +346 | 1,389 |
| Prince of Wales | −1,075 | — | — |
| Rotherham Main | −1,165 | — | — |
| Monkton Main | −1,189 | — | — |
| Mansfield ... | −1,241 | −83 | 1,158 |
| *Ackworth ... | −1,250 | — | — |
| Denaby Main... | −1,273 | — | — |
| Shirebrook ... | −1,289 | +143 | 1,432 |
| Rufford ... | −1,335 | −250 | 1,085 |
| Warsop Main... | −1,339 | +22 | 1,361 |
| Langwith ... | −1,339 | +55 | 1,394 |
| *Shire Oaks ... | −1,370 | −64 | 1,306 |
| Barnborough ... | −1,400 | — | — |
| Hickleton Main | −1,437 | — | — |
| Houghton Main | −1,449 | — | — |
| Steetley ... | −1,548 | +41 | 1,589 |
| *Clipstone ... | −1,555 | −270 | 1,285 |
| Grimesthorpe... | −1,583 | — | — |
| Askern Main ... | −1,624 | −70 | 1,554 |
| Hemsworth ... | −1,620 | — | — |
| Thurcroft ... | −1,641 | — | — |
| Brodsworth Main | −1,654 | −61 | 1,593 |
| Dinnington ... | −1,656 | — | — |
| South Kirkby... | −1,700 | — | — |
| Bentley ... | −1,847 | −500 | 1,347 |
| *Welbeck ... | −1,860 | −275 | 1,585 |
| Frickley ... | −1,895 | — | — |
| Bullcroft Main | −1,986 | −332 | 1,654 |
| Manton ... | −2,034 | −500 | 1,534 |
| Cadeby Main... | −2,043 | — | — |
| Maltby Main ... | −2,194 | +82 | 2,276 |
| Selby ... ... | −2,230 | −1,268 | 962 |
| *Wallingwells .. | −2,349 | −100 | 2.249 |
| *Hatfield Main | −2,400 | −1,083 | 1,317 |
| *Yorkshire Main | −2.551 | −182 | 2,369 |
| Cantley ... | −2,555 | −980 | 1,575 |
| Rossington Main | −2,582 | −525 | 2,057 |
| Thorne ... | −2,736 | −1,518 | 1,218 |
| Haxey (South Car) ... | −3,115 | −1,719 | 1,396 |

The depths given for the pits marked with an asterisk are only approximate.

In using the method of triangles for ascertaining the run of the contours from these 113 available spot-levels of the Barnsley Bed, limitations to the method are soon discovered, and one finds that only over relatively small districts (rarely much more than half-a-dozen miles across) do the groups of adjoining triangles appear to indicate an unchanging direction for the lines of strike.

As already mentioned, the method is strictly applicable only when the condition, that over the area represented by each triangle the surface is a plane lying uniformly between the points represented by the three apices, is satisfied. If, then, instead of a plane, the surface on which three haphazard points are taken is really a part of a cylinder, a dome, or a basin, or, which is worse, is broken by one or more faults into a series of steps, the geometry of the plane which passes through the three points the positions of which are known will give a very incomplete, and possibly erroneous, representation of the real average conditions as they are within the area. Fortunately, a great deal of the area under discussion is exposed coalfield, and strata quite conformable with the coal-seams can be inspected at the surface of the ground. Moreover, the coalfield is in course of active exploitation, and actual coal-workings have proved the geometry of the Coal-Measures over areas which form a very considerable proportion of the whole. Such mining information, as well as that obtained by the hammer and the clinometer of the geologist, enables us to check inferences obtained by the three-point method, and if it appears that the apices of particular triangles are unfavourably placed, the contours which might seem to have been indicated within the area of any one of those triangles may be discarded.

In the actual drawing of the contours of the Barnsley Bed and Top Hard Coal on the present map, there has been no case which has necessitated total neglect of any triangle, and although a freer "humouring" and sketching in of the contour-lines as they curve in and out among certain points which are disposed along the troughs and arches of known folds, or on opposite sides of well-proven faults, has been allowed than was necessary in representing the evenly-spaced contours of the base of the Permian, the total amount of non-geometrical adjustment required has not been considerable.

If we view now the contours as they appear, smoothed out, and spaced as evenly as possible according to the mining and other available geological information, it will be noted that within the area in question (so far as exploration concerning which the results have been made public has extended) the slope of the surface, although irregular, has always a component to the east. The shallower contours appear to follow the run of the coal outcrop with approximate parallelism, but contours belonging to greater depths, although evidently bending with the shallower ones, and curving round anticlinal or synclinal disturbances which have axes with orientations similar to those that affect the outcrop of coal, in detail depart considerably from exact parallelism with the direction of that outcrop. The wider separation of the contours in depth, as compared with those near the outcrop, is a striking feature of the map, and especially noticeable wherever the strike of the contours tends north-westwards.

With respect to the courses of the individual contours, a study of the map in association with the foregoing table provides the best available information, and the writer will only further discuss them in so far as the localities in which they change their directions give evidence of the amplitude and continuity of the disturbances due to the earth-movements which have affected the field. It may be noted in passing that only in the district south of Chesterfield have the measures which include the coal under discussion been hard enough to resist denudation sufficiently to bring the place of the contour of +100 yards beneath the present surface of the ground.

In studying the disturbances the writer will begin with those which affect the country in the south. The geology of this district as far as the Yorkshire border has been revised by the Geological Survey within the present (twentieth) century, and the details of its structure have been described at some length by Gibson in the Memoir on "The Geology of the Northern Part of the Derbyshire Coalfield: Explanation of Sheets 112 and 100." The more important of the disturbances in this southern district have axes ranging north-west and south-east. Southernmost among them is the Ripley syncline, the north-western end of which extends beyond Alfreton, but dies away before it reaches the line of outcrop of the Silkstone Coal at

Stretton. The outlying patch of measures containing the Top Hard Coal about Swanwick and Alfreton owes its preservation to its being down-folded as a shallow trough between bounding faults which define the north-eastern and also the south-western margins of this syncline.

From Pinxton by Blackwell to Tibshelf the outcrop of the Top Hard Coal follows a sinuous course, and the beds dip eastwards very gently. Between Blackwell and Silver Hill, and about Sutton, the strike appears to bend a few points eastwards. This eastward swell, which might be termed the beginning of the Mansfield anticline, affects all contours down to −500 yards, and possibly −600 yards, carries each one successively farther eastwards of its average line, and accounts for the advantageous mining conditions which in recent years have been experienced at the great pits of Sherwood, Mansfield, and Rufford.

The evidence provided by pits and borings on the south beyond the area of the map suggests that on the south-east this east-and-west Mansfield anticline is cut off by a sharp north-easterly and south-westerly synclinal trough which contains unprofitable red and green measures belonging to the Upper Coal-Measure Series, such as were proved at Oxton and Thurgarton. The published evidence from the Kelham boring,* which is also just south of the boundary of the map, may be interpreted as suggesting that a trough through Farnsfield is followed by an eastward rise of the measures in the district to the east of it.

In following the axis of the eastward swell of the contours between Tibshelf and Rufford along a line of latitude immediately south of Mansfield, one must not lose sight of the existence of the north-western and south-eastern syncline through Barlow and Chesterfield. This Chesterfield syncline contains measures above the Silkstone Coal, and flanks the Brimington anticline on the south-west. Possibly it is the disturbance of this trough-line encroaching upon the Brimington anticline which brings the Top Hard Coal within the faulted syncline of Williamthorpe, and produces the curious outline of the outcrop of that coal from the upper valley of the Doe round by North Wingfield to Grassmoor in the valley of the Rother. South of Holmwood, the Williamthorpe syncline is supposed to lose itself in faults, and

* "The Search for New Coal-fields in England," by A. Strahan, *Proceedings of the Royal Institution of Great Britain*, weekly evening meeting, Friday, March 17th, 1916, page 6.

Gibson has suggested that beyond it the Brimington anticline may reassert itself and "pass between the borings at Oxton and Thurgarton and that of Kelham."* From the trend of the contours, it would seem that the only place for any continuation of the Brimington anticline south of Stainsby is the crest-line through Sutton and South of Mansfield which the writer has already discussed.

From Silver Hill and Teversal northwards to Staveley, the contours of shallow depths trend steadily to the north-west, and are very close together, a dip of almost 1 in 2 being indicated about Glapwell, the workings of which flank the southern end of the main Brimington anticline. Through Ireland, Markham, and Bolsover Pits the line of the Dronfield-Stavely syncline (which is its north-eastern neighbour) is continued, but the effects of this are complicated and somewhat reduced by a subsidiary anticline through Oxcroft and between Shirebrook and Warsop, which separates it from the main trough that passes south of Creswell to Langwith, and in the deepest part of which the new pit at Welbeck seems to have been sunk.

The wide bay in the outcrop of the Top Hard Coal about Renishaw is on the line of the anticline of Norton—Ridgway. The line of this disturbance continues north of Barlborough through Whitwell, and in its relations with the Dronfield—Langwith syncline determines the southerly or south-easterly dip of the coal at Creswell and Southgate. Steetley lies on the northern flank of this disturbance, and the crowding of the −300, −400, and −500-yard contours to the west of that pit suggests that its acuteness has not decreased south-eastwards.

Waleswood, Aston, Beighton, Fence, Handsworth, Orgreave, Treeton, High Hazels, and Tinsley Park Pits lie among contours quite as regularly as any spot-levels determined for the plane at the base of the Permian. Norwood, West Kiveton, and Kiveton Park are deeper than would be estimated from a knowledge of the depths in Yorkshire, and evidently lie south of their proper position as determined by producing south-eastwards the straight-line contours drawn among the pits of Rothervale. The effect is as of an anticline along the line of the Sheffield-Worksop railway, and a comparison of the depth at Shire Oaks with depths

* H.M.G.S. District Memoir *On the Geology of the Concealed Coalfield of Yorkshire and Nottinghamshire*, by W. Gibson, 1913, page 39.

at Steetley and at Manton suggests that the displacement due to such an anticline increases rather than diminishes eastwards.

Between the county boundary of Yorkshire and the neighbourhood of Sheffield the regularity of the shallower contours has already called for comment. In this area the Top Hard Coal thickens northwards, and, becoming more bituminous, is counted worthy of the name of the "Barnsley Bed." In this district the dip near the outcrop is steeper than the average, and the widening of the spaces between the deeper contours is particularly marked. The direction of the strike is some few degrees more westerly than in any other district shown upon the map (Plate VII.). The deeper contours shown have had to be drawn between spot-levels that are very far apart, and the experience gained at Thurcroft causes one to expect that, when the details become known, bends and other irregularities, perhaps of considerable amplitude, will be required to represent the true underground geometry of the central and eastern parts of the district.

Through Sheffield, by Rotherham to Hooton Roberts and Conisborough, ranges the well-known disturbance always referred to as the disturbance of the "Don Faults." This is a belt of country more than a mile in width, across which a proved succession of not very considerable faults and very important variations in the amount and direction of the dip bring about a change of level equivalent to a vertical displacement of the measures by some 400 or 500 yards.

Usually, in alluding to this displacement, one lays stress on the throw of the faults known respectively as the "Northerly" and the "Southerly" Don Faults; but when, after an inspection of mining plans and a study of the ground, one has made a number of horizontal sections across them to true scale, the greater general importance of steep dips compels notice; and one concludes that the whole disturbance is better regarded as the steep and somewhat broken middle limb of a monoclinal fold. A geometrical plotting of the depths at Holmes, Car House, Aldwarke Main, Roundwood, Thrybergh Hall, Denaby Main, and Cadeby Main Collieries also gives evidence in favour of the same view, which has therefore been adopted in the making of the map. From the map it will be seen how regularly the average slopes continue despite the faults, and by it a proper emphasis is placed upon the general steep south-easterly dip

within the faulted zone. The axis of the synclinal trough related to the Don Faults disturbance appears to range somewhat north of east through Rotherham Main and between Silverwood and Maltby Main. The behaviour of the dip at Maltby and the great depth of Yorkshire Main Colliery might suggest that the centre of the trough occurs somewhere between Maltby and Doncaster; but the dip at Rossington Main and the depths given by borehole information at Armthorpe, Cantley, and South Car make it probable that the main deep trough really trends south-eastwards. From the geological map it is evident that Yorkshire Main was sited on a foundered keystone between a pair of faults, and the great depth at that pit may therefore be more of local than of general significance.

To the north of the Don Fault disturbance the north-westerly strike and north-easterly dip which are usual over the greater proportion of the exposed part of the coalfield in South Yorkshire are resumed, and it is seen that the general effect of the displacement is to set back the lines of the contours by a distance of some 6 miles to the north-east. Near the outcrop of the Barnsley Bed the step is a very sharp one, and the angles of the Z-bend made by the sea-level contour are approximately right-angles. Contours of intermediate depth (−300 yards) about Manvers Main and Wath Main evidently swing round more smoothly, and in the district of the deeper pits north of Doncaster, where the spaces between successive contours is much wider, what evidence is available is in favour of the change of direction (which in that district is through somewhat more than a right-angle) taking place continuously along considerable lengths of widely sweeping curves. The contours north of the Don Faults assume, in fact, the form of a pitching monocline, which to the east passes into a narrower, but still broad, arch of an anticline of less uncommon form. That the displacement due to it dies out completely in a north-easterly direction is improbable, and it is the opinion of the writer that, along the continuation of its line for many miles north-east of Doncaster, the coals occur at levels always considerably shallower than in the neighbouring country to the south.

Of the course of the Don Faults disturbance south-west of Sheffield there is little information. Of the actual faults Green has stated that they end off against other north-west-trending

faults within the area of the city.* That the whole disturbance thus comes abruptly to an end is improbable, and it may be pointed out that the outcrop of the Gannister or Halifax Hard Bed along the valley of the Don and Little Don above Sheffield is no less out of line with that of the same bed across the Derbyshire moors south of the city than is the outcrop of the Barnsley Coal in Wentworth Park out of line with that at Handsworth and Woodhouse in the country south of the Don. It is even probable that the disturbance extends south-westwards across the whole outcrop of the Millstone Grit, and quite possibly the south-westward step in the outcrop of the Mountain Limestone between Calver, Great Longstone, and Bakewell may be a continuation of the same disturbance.

Within the district of the uplifted monocline north of the Don disturbance, as far as the latitude of Barnsley, the structure of the country is of simpler type, and such local bends as affect the north-west-ranging contours (for example, at Elsecar) are due to normal block-faulting by dip- or strike-faults, probably related to the main disturbance. Except just east of Barnsley, the contours belonging to shallow depths appear much closer together than those at greater depths. East of Barnsley there is an evident crowding of all the contours down to −500 yards; and although surface relief largely accounts for the slight westward swell of the outcrop west of the town, it is clear that between Barnsley Main, Grimethorpe, and Frickley an important synclinal trough or basin is developed, with a more or less well-defined opening by Bullcroft out to the east. This wide and open trough, to which the name " Frickley Trough " is very applicable, is the main tectonic feature of the coalfield north of the Don Faults. Its course is well defined by the contours −500 and −600 yards between Brodsworth Main and Askern Main, and as it ranges further eastwards it appears to encroach upon and perhaps in part to help the rounding-off of the monoclinal feature of the Don. It may be also that the north-westerly strike of the Coal-Measures which has been proved at Hatfield Main has been produced by it. Along the westward continuation of the line of the Frickley Trough a rather sharp anticlinal swell through Wharncliffe Woodmoor and Carlton Main causes the trunk syncline to divide into a south-westerly and a north-westerly

* H.M.G.S. District Memoir *On the Geology of the Yorkshire Coalfield*, by A. H. Green, R. Russell (and others), 1878, page 490.

trending arm. The south-westerly branch is that which trends through Grimethorpe and Barnsley Main, the effects of which have just been described. The north-western limb is wider and less well defined, but can be traced through Havercroft and Ryhill Main, south of Sharlston West, to Wakefield, and by its continuation may account for the preservation of the great expanse of rocks newer than the Silkstone Coal in the country west and north of Dewsbury. A further trough, also ranging north-westwards, seems to branch from the Frickley Trough east of South Kirkby, whence it may range as far as Rothwell. Hemsworth, Nostell, Sharlston, and perhaps St. John's, are on the line of it; but, as the writer will demonstrate shortly, faults in the district about Normanton render its further continuation difficult to trace.

Of all the pits sunk through Permian limestone to the Barnsley Coal in Yorkshire, there has been none at which the depth was more unexpected than that at Askern Main, which is as yet the only point whence one can fix the trend of contours across the 8 or 9 miles of country between Hemsworth and Pontefract and the Frickley Trough. North-eastward from Askern, beneath the Permian Limestone, only the strike-lines of the triangle formed by Askern Main, Fryston, and Selby are available as guides. From Selby, moreover, the evidence is not very satisfactory, and the depth assumed—2,245 feet—is adopted on the strength of the guarded statement by Gibson,* who, having recognized "fragments of *Goniatites* in a pale bluish shale at 1,775 feet," expresses the opinion that "presumably" it belonged to "one of the bands above the Barnsley Coal, which in the form of the Warren House Seam may have been passed through in the faulted ground at a depth of 2,261 feet." Within the triangle so determined the contours have merely been spaced out regularly, and are only inflected just sufficiently to make them join with the better-proved lines in the country to the west. Evidently, if Gibson's tentative view about Selby is right (and the rumours spread concerning Pollington tend to confirm it), the average strike of the Coal-Measures under the Permian limestone between Selby, Hatfield Main, and Pontefract must be more nearly north and south, and the average dip more easterly than the trend which the contours in the exposed coalfield in West Yorkshire would have led one to expect.

* H.M.G.S. District Memoir *On the Geology of the Concealed Coalfield of Yorkshire and Nottinghamshire*, page 68.

From the Don Valley past Barnsley to Darton the outcrop of the Barnsley Coal maintains a regular north-westerly direction, and faults (where present) are not of sufficient magnitude to deflect its course. Beyond Haigh and West Bretton, just where the coal-seam again changes its character, and, taking on its West Yorkshire facies, becomes the Warren House Coal in the east and the Gawthorpe Coal in the west of the district, the structure of the coalfield alters, and normal cross-faulting (often on a considerable scale) becomes the rule. By this faulting the country is cut up into more or less rectangular blocks with sides making average angles of 45 degrees with the meridians, and outcrops cease to be traceable continuously from one block to another. In following the boundary of the measures newer than the Barnsley Coal across this imbricated country, from Crigglestone, by Horbury, Ossett, East Ardsley, Lofthouse, and Woodlesford to Kippax, where they disappear beneath the escarpment of the Permian, we find that generally, wherever the trend of the boundary line is north-eastwards, it takes that direction by following the course of some more or less important fault. Within the boundary the contours, drawn to fit the spot-levels from the pits in the foregoing list, follow a general trend quite parallel to the north-east-ranging faults, and only when one asks about dips and strikes as proved by workings at the various collieries, does one come to know how little direct evidence there is, over this most important West Yorkshire mining district, of any general or consistent south-easterly dip. Nevertheless, when one consults the Geological Survey map one sees that between Lofthouse and Sharlston, or between Allerton Bywater and Pontefract, higher measures do come in south-eastwards, and on close enquiry one finds that a rather regular succession of north-easterly to south-westerly faults, each throwing down south-eastwards after the manner of a step- or cascade-like structure, does really simulate and produces the same average displacement as would a persistent dip to the south-east. Among such broken structures the proximity or otherwise of the pit-sites to the faults has considerable influence in determining the way in which the contours have to bend among them, and too much reliance cannot therefore be placed on the minor irregularities which in this district certain of the contours seem to show.

(5) *The Pre-Permian Contours of the Barnsley Bed.*

Having described and attempted to justify the courses suggested for the contours of the base of the Permian and of the Barnsley Bed, the writer may now deduce, by the simple process of subtraction, the heights above the Barnsley Bed of the surface upon which the Permian rocks were deposited. For this two kinds of evidence are available, namely :—

(1) The direct evidence provided by such shafts and boreholes as pierce both the base of the Permian and the Barnsley Bed. From such records, by the subtraction of the number taken as the depth to the base of the Permian from that of the depth to the Barnsley Bed, a new series of numbers is obtained, which, if distributed with sufficient regularity, may serve as spot-levels for the running of contours in the manner previously described.

(2) The indirect evidence obtained by the study of the contours already plotted, bearing in mind the geometrical property of contours by which, if two series of such lines, both drawn with the same arbitrary but convenient interval between their successive members, should intercross, the difference of height between the two sets at a pair of opposite corners of each quadrilateral of the net formed by their crossing must always be the same, and the diagonal (not necessarily a straight line) joining these two corners must represent a contour of equal differences. By joining, then, the pairs of opposite corners of all the various spaces of the net formed by the intersection of the pre-Permian and the Barnsley surface contours, and softening the angularity of the lines, a series of contours recording the variations of the depth of the Barnsley Bed below the Permian within the area over which the Permian rocks occur is obtained. Fig. 2 (Plate VIII.), showing the contours for (1) the base of the Permian, and (2) the Barnsley Bed, was prepared by tracing directly the contours as plotted on the half-inch map, and subsequent reduction by photography.

For Fig. 3 (Plate VIII.) the tracing used for Fig. 2 was worked upon, and diagonals showing the lines of constant difference were drawn in across the spaces of the net, half- and quarter-way contours being freely sketched in order to show the intermediate points of intersection wherever there was a doubt, and where the sweetening of an awkward bend of the diagonal in the midst of a quadrilateral, the sides of which are more than usually

out of straight, was required. The new curves also were slightly adjusted, where necessary, into complete agreement with the direct evidence afforded by all available boreholes, and were then re-traced ready for reduction by photography, to form the eastern half of Fig. 3.

The direct measurements made use of in controlling the contours of this diagram are, in order of increasing differences, as follows:—

| | Feet. | | Feet. |
|---|---|---|---|
| Fryston ... ... ... | 467 | Warsop Main ... ... | 1,361 |
| *Sutton ... ... ... | 600 | Pleasley ... ... ... | 1,389 |
| *Barlborough ... ... ... | 605 | Langwith ... ... ... | 1,394 |
| Whitwell ... ... ... | 765 | Haxey (South Car) ... | 1,396 |
| Southgate ... ... ... | 873 | Shirebrook ... ... ... | 1,432 |
| Kirkby ... ... ... | 903 | Manton ... ... ... | 1,534 |
| Selby ... ... ... ... | 972 | Askern Main ... ... | 1,554 |
| Sherwood ... ... ... | 1,038 | Cantley ... ... ... | 1,575 |
| Creswell ... ... ... | 1,085 | Welbeck ... ... ... | 1,585 |
| Rufford ... ... ... | 1,085 | Steetley ... ... ... | 1,589 |
| Mansfield ... ... ... | 1,158 | Brodsworth Main ... ... | 1,593 |
| Thorne ... ... ... | 1,218 | Bullcroft Main ... ... | 1,654 |
| *Clipstone ... ... ... | 1,285 | Rossington Main ... ... | 2,057 |
| Shire Oaks ... ... ... | 1,306 | *Wallingwells ... ... | 2,249 |
| *Hatfield Main ... ... | 1,317 | Maltby Main ... ... | 2,276 |
| Bentley ... ... ... | 1,347 | *Yorkshire Main ... ... | 2,369 |

The thicknesses given for the pits marked with an asterisk are only approximate.

To the west of the Permian outcrop, the completion of the contours showing the depth of the Barnsley Coal below the base of the Permian is founded on more theoretical evidence, which depends upon an exterpolation of supposed contours for the base of the Permian over the area from which all trace of Permian rocks *in situ* has long been removed. Nevertheless, because the geometry of the known surface at the base of the Permian has been proved to be simple, and its contours are spaced so regularly over the whole of the area shown on the map (Plate VII.), and because the geometry of the Barnsley Bed in the exposed coalfield has been so completely proved by mining, the writer has thought well to undertake the exterpolation and to put on record the results. The method of exterpolation for the contours of the base of the Permian beyond its outcrop was as follows:—On the tracing from which Fig. 2 was prepared, lines were drawn along the direction of full dip (that is, at right-angles to the contours of the Permian) at such intervals as to cut the area into squares, and these dip-lines were continued out over the exposed coalfield. Along these lines distances were marked off which to the eye seemed not out of harmony with the average distances within the Permian ground, and through the points so found

hypothetical contours for lines at successive hundreds of yards over the country as far westward as the Barnsley Bed outcrop were drawn in. These sketch-contours were then treated as if they had been obtained by more direct observation, and through the net of their intersections with the proved contours for the coal-seam diagonals were drawn as before, and traced off to complete the diagram (Fig. 3) in continuity with the lines of equal differences east of the Permian outcrop. As already shown (see Fig. 2), the courses of all contours of the pre-Permian surface between that of +200 yards in the outliers west of Mansfield, and that of −800 yards along the lower course of the Trent, are fairly well known. By exterpolation it would seem that, if similar slopes are continued westwards, the base of the Permian would be carried to +400 yards about Wakefield, to +500 yards at Barnsley, and to +600 yards in the neighbourhood of Sheffield, where is the highest exterpolated contour which the area dealt with on the map requires.

With respect to the shapes which these contours of equal differences take, a glance at the map (Fig. 3, Plate VIII.) will convey more information than a long description. One feature which the eye notices immediately is that the alignment of centres round which circle the lines of greatest differences is along a north-western and south-eastern line through Leeds and Worksop. Of the two well-marked widely open basin structures the one has its centre at Brierley Common, about midway between South Kirkby and Grimethorpe Pits; the other, which is situate south of the Don Fault disturbance, has its centre near Bramley, not far from Maltby. In the central areas of each of these basins the thickness of Coal-Measures which remained above the Barnsley Bed when the Permian rocks were deposited must have exceeded 700 yards over several scores of square miles, and in the Maltby basin over a considerable area the thickness that actually remains is more than 800 yards. South of the Yorkshire boundary the cover of Coal-Measures above the Top Hard Coal is generally thinner, and nowhere is there any direct evidence that it attains 600 yards. Within the parts of the area which belong to Derbyshire and Nottinghamshire it would appear that distribution of the contours of equal thicknesses of Coal-Measures is entirely dependent on the disposition of the north-west-trending ridges of Mansfield and

Brimington, of Barlborough, Ridgway and Norton, and of Kiveton Park, the courses of which the writer has already discussed. There is some evidence that at Steetley and Manton, and at Welbeck, at each of which localities more than 500 yards of Coal-Measures have been proved, the pits are situate not far from the centre-lines of the troughs which come between these anticlinal disturbances.

Concerning individual contours, the situation of a zero-line, which is the line in which the base of the Permian meets and cuts off the Barnsley Bed, may first be noted. Direct evidence for the junction is nowhere seen, but in the south the outcrop of the base of the Permian crosses the line which has been taken as the outcrop of the Top Hard Coal beneath the Permian outlier about a mile east of Tibshelf; and it seems probable that, before the present cycle of denudation, the Permian must have rested on measures older than the Top Hard Coal a mile or two further north near Hardstoft, and also on the west side of the Williamthorpe Syncline, as well as for some distance along the crest of the Brimington Anticline. In the district from South Elmsall northwards the Permian begins the transgression which carries it across all members of the Middle and Lower Coal-Measures and the Millstone Grit Series, and near Richmond brings it to rest directly on the Carboniferous limestone. The place of the actual transgression of the outcrop of the Warren House Coal by Permian rocks is obscured by the Kippax Fault, but lies south of, and cannot be far from, the Ledstone Luck Pit. Beneath the Permian the line obtained by intersections of the Permian base and the Barnsley Bed contours ranges eastward by South Milford before it takes the north-eastward turn which the accepted interpretation of the Selby borehole demands.

The contours of 100, 200, 300, and 400 yards may be considered together. In the south they course round the Mansfield Anticline, taking on an outline not unlike the body of a swan, the neck of which is extended north-westwards along the ridge of Brimington. The line of 200 yards comes in again at Renishaw, and, followed by those of 300 and 400 yards, demonstrates the continuation of the Norton—Ridgway Anticline in that of Barlborough. The double inflection of the 500-yard line about Worksop may be an accidental feature; but it draws attention to the circumstance that, if the disturbance which

affects the Permian outcrop at Kiveton Park were flattened out, the bend of the present contours of the Top Hard Coal below it would be considerably accentuated. In South Yorkshire the contour of 200 yards appears only between Parkgate and New Stubbin as topping the crest of the Don Fault disturbance. The 300-yard line, and with it the 400- and 500-yard lines, follow the course of the Don from Attercliffe almost to Kilnhurst before they bend round somewhat sharply westwards to form the southern lip of the Brierley Basin. The increase of cover shown by the crowding of five contours into the mile or so of country between Roundwood and Silverwood is evidence enough of the abruptness with which at its north-western edge the bowl of the Maltby basin ends off against, or is cut off by, the Don Fault disturbance. From Tankersley to Ossett the contour of 400 yards passes along or west of the outcrop of the Barnsley Coal, and only the deeper lines for 500, 600, and 700 yards appear within the area contoured to indicate the shape of what was evidently the basin with the widest westward extension in the North Midland coalfields.

The eastward bend of the lines north of Barnsley appears to be determined by the north-westerly anticline through Wharncliffe Woodmoor, which makes an evident bulge in the side of the main basin. The ridge through Snydale makes a similar bulge, but the embayment which succeeds it on the east fails to affect the contours of thicknesses less than 500 yards, which, as far as the northern boundary through Ledstone Luck (previously discussed), course very regularly east and west across all that part of the exposed coalfield that lies north of a line joining Wakefield and Pontefract. Further east, within the Magnesian Limestone area, the contours of small thicknesses must lose their parallelism, and, in agreement with the thicknesses of Coal-Measures actually sunk through at Askern Main and other pits north of Doncaster, those for thicknesses greater than 500 yards sweep round southwards and ultimately south-westwards, thus completing the encirclement of the south side of the Brierley Basin. How the lines for thicknesses smaller than 500 yards behave in the region north of Askern Main is a problem which the evidence before the writer does not solve; and, though the lines as plotted have been obtained by joining the requisite points on the net of intersections, the contours for the surface of the Barnsley Bed, which form one set of strands of that net, were sketched in on

such insufficient evidence that, before venturing upon any dogmatic statement, one must wait for more direct information which can only be obtained from boreholes or pits which may be sunk within the area in question. In any case, if the lines are to be made to tally with the published results of the boring at Selby, it is evident that somewhere about Pollington they must bend back north-eastwards rather sharply. Thus bending, they may be taken to suggest the beginnings of a further north-eastern trough or basin centred in the district between Snaith and Goole, concerning which, though rumour says that it contains a considerably greater thickness of Coal-Measures newer than the Barnsley Bed than has yet been placed on record, no trustworthy information has so far been made public.

In discussing the probable eastward limits of the concealed coalfield, Gibson* has well emphasized the importance of the general eastward thinning of the Coal-Measures below the Permian in the district north of Doncaster. The ranging of the contours of equal thickness among the pits of the district shows well the truth of his contention, notwithstanding that Bullcroft Main and Askern Main have both greater thicknesses than Brodsworth Main, which lies a mile or so to the west of both of them. The contours also show that the maximum rate of variation is not by any means always strictly to the east. A tongue of thinner measures, as indicated by the 400-yard line, seems to occur within the district ringed round by the sites of the boreholes at Thorne, Armthorpe, Cantley, and South Car, and adjoined by the pits of Hatfield Main and Bentley; but, whether this promontory is a detached outpost, or is really a spur projecting inwards from the eastern margin of the whole coalfield, further exploration alone can show. Meanwhile, the hypothesis may be put forward that beyond Thorne the 400-yard contour turns again eastwards, and, forming a *col* with its neighbour somewhere about Sykehouse, gives space for other lines which will indicate thicker measures in the trough or basin of the Snaith and Goole district.

For the determination of the eastern limits of the Maltby basin, the evidence is hardly yet before us, although if we judge from the results obtained at the sinkings of Yorkshire Main and Rossington Main, and from the boreholes at South Car and Cant-

* H.M.G.S. District Memoir *On the Geology of the Concealed Coalfield of Yorkshire and Nottinghamshire*, page 44, and fig. 3, page 45.

ley, it seems reasonable to express an opinion that the trend of the main extension will be south-eastwards. The results obtained by the boring at South Leverton are quite in keeping with the same suggestion, and it is reasonable to expect that in the district some few miles south of Gainsborough the measures containing the Barnsley Bed may be continued eastwards beyond the line of the River Trent. Concerning the borings over the intermediate district south of Maltby, little information has been made public since the time of the Survey memoir on "The Concealed Coalfield;" and only remarking that the Wallingwells borehole has confirmed the continued great thickness of the Coal-Measures between the Permian and the Barnsley Bed south-east of Dinnington, the writer will leave the question of the thickness of the measures, which separate the horizon of the Barnsley Bed from the base of the Permian in the central part of the coalfield which lies further south.

### (6) *Interpretation of Statistical Results.*

So far, in dealing with the measured differences of depths and thicknesses proved in mining, the writer has treated them merely as inert numbers distributed fortuitously at defined points scattered over a determinate area. By drawing contour-lines among these numbers, he has given graphic expression to their ordered arrangement, and therefore to the laws that govern their distribution, which distribution the maps have proved to be neither intricate nor especially simple. It now remains to interpret these statistical results in terms of tectonic structure and of the geological history of the area dealt with.

In undertaking this, the writer will begin by making the assumption that the surface on which the Permian now rests was once a uniform and horizontal plane. If, and in so far as, this assumption can be accepted, it must follow that the general slope and all the irregularities which the contours of the base of the Permian now show have been produced by tilting and by various incidental crumpling movements, all of later date than the time of the deposition of the Permian rocks; and, since the causes of earth-movement are deep-seated, and no space can long remain open within the crust of the earth, it must also follow that with the Permian rocks when they were tilted, bent, and broken, the Coal-Measures beneath them were also affected, and raised

or lowered vertically to the same extent. On this assumption the contours drawn to record the distribution of the differences of level between the base of the Permian and the Barnsley Bed must be identical in form with the contours which had been impressed upon the Barnsley Bed before the Permian was laid down, and Fig. 3 may be regarded as a fair expression of what is known of the form which the Barnsley Bed had taken at the beginning of Permian time. If contour-lines drawn for equal thicknesses of the beds between the Barnsley Coal and the base of the Permian, with some constant added to express and correct for the height of the pre-Permian surface-level above or below Ordnance datum, be accepted as the contour-lines of the Barnsley Bed in pre-Permian time, then do these same contour-lines become the strike-lines, and all lines drawn at right-angles to them show the direction of full dip of the Coal-Measures as they were lying at the time when the Permian was laid down.

Whether in actual fact the pre-Permian surface at the beginning of Permian time can be accepted as a flat area quite devoid of general slope, is a matter only to be settled by the accumulation of geological evidence, and which provides a subject demanding much further research; but certainly neither the recent work of the Geological Survey in Derbyshire and Nottinghamshire, nor any observations which the writer has been able to make in Yorkshire, have provided any suggestion of irregularities—other than those due to evident and well-recognized post-Permian folding or faulting—large enough to be shown by contours drawn at vertical intervals of 100 yards on a map of so small a scale as ½ inch to the mile.

Such evidence as there is of original irregularity in the pre-Permian surface is provided by the patches of sand that occur at intervals along the Permian outcrop: these were once extensively quarried, sometimes for glass-making, sometimes for moulding-sand. Similar sand-pockets when they occur within the outcrop behave as quicksands, and at certain of the new pits they have given trouble to the sinkers as the shafts were passing from the Permian to the Coal-Measures. These sand lenticles or pockets, although they certainly rest in hollows eroded into the surface of the Coal-Measures, are rarely more than a score of feet in thickness, and the continuity of the regular bedding of the Marl Slate and Magnesian Limestone as it extends

over and beyond the edges of the patches is proof enough that the hollows in which the sand occurs are quite minor features, having little relationship to the general form of the pre-Permian country as a whole.

The question of the general slope of the surface is rather a wider one, and the evidence bearing on it must be sought in the study of the unconformity and overlap of the Permian rocks over a very wide stretch of country. Comparisons of records of total thicknesses of Permian rocks proved at far distant points along a north-and-south line—for example, Nottingham (50 feet) and Hartlepool (900 feet)—120 miles apart, show an average northerly thickening of these rocks of about 7·5 feet per mile. A similar comparison of the records along an east-and-west line, as Manton (400 feet) and South Leverton (526 feet), which are 12 miles apart, proves an eastward increase of thickness of about 10 feet per mile, and there is, consequently, reason to expect a general north-easterly thickening of the rocks at the rate of about 12·5 feet per mile. From this it is possible to argue that, since such north-eastward thickening of the Permian rocks may be due to overlap by successive beds or sheets of Permian rocks which overstepped one another south-westwards against a sinking shore-line, a correction for this north-eastward slope ought to be applied; and that, until such correction has been made, the forms of the contours obtained by the statistical process of subtraction can hardly be accepted as really representing the pre-Permian contours of the Barnsley Bed. A slope of 12·5 feet per mile north-eastwards is equivalent to a distance of 24 miles between successive contours drawn at vertical intervals of 100 yards, and although by drawing north-west-ranging lines a foot apart over the tracing from the ½-inch map, and constructing diagonals for the net of the intersections which such lines make with the contour-lines as at present drawn (Fig. 3), we might be able to make some slight correction, it does not appear that the consequent refinement, which might be expected from the results to be so obtained, is worth the trouble of reconstructing the map, and therefore the diagram (Fig. 3) has been allowed to go forward without this correction.

Considering now this map as showing the pre-Permian contours of the Barnsley Bed, it is unnecessary again to describe the shapes which the contours take, though perhaps it may be

desirable to call attention to the general form of some of the leading structures, more especially to the north-western and south-eastern alignment of the great basin structures of Yorkshire as they lie on each side of the Don Fault disturbance.

A line joining the centres of the basins at Brierley and Maltby, continued north-westwards, passes through Leeds. Continued south-eastwards, it passes between Steetley and Manton, a little east of, and not far from, Welbeck, and crosses the southern boundary of the map between Farnsfield and Kirklington. It will be interesting to ascertain whether the troughs which intervene between the anticlinal swells of Barlborough and of Mansfield contain also their maximum thickness of Coal-Measures along this line. The north-west and south-east direction of the alignment of the basins is in itself interesting, in that it is parallel with a line drawn through the inliers of the old rocks near Ingleton in North-West Yorkshire, and the perhaps even more ancient rocks of Charnwood Forest; a line along which the Pre-Cambrian rocks of Charnwood in pre-Cambrian times were compressed in tight folds, cleaved and over-faulted—the line, in fact, of "Charnian" trend.

So far as the present writer has been able to ascertain, it is to Prof. Kendall that the credit is due of having first drawn the attention of those concerned to the importance of the Charnian axis in determining the main outlines of the North Midland Coalfield.* Having noted numerous examples of the recurrent instability of the Charnian axis as it affects various rocks later in date than the Coal-Measures, its continuations south-eastwards beyond Bletchley, in Bedfordshire, and north-westwards at least as far as Ingleton, and its proved relationship to the edge of the coalfield between Nottingham and Leicester, Prof. Kendall states, with respect to the pre-Permian movements, that—

"At the close of Coal-Measure times this chain seems to have formed a strong rib or buttress against which the movements affecting newer rocks broke, and their only effect seems to have been to raise the old chain anew and rear it as a barrier over which the Carboniferous rocks were bent, and to separate two areas of Permian deposition, an eastern of limestone-deposit from a western of, mainly, red sandstone and marl." †

* "Sub-report on the Concealed Portion of the Coalfield of Yorkshire, Derbyshire, and Nottinghamshire," by Prof. P. F. Kendall, Appendix iii. to the Geological Committee's Report in part ix. of the *Report of the Royal Commission on Coal Supplies*, 1905, pages 18 *et seq.*

† *Op. cit.*, page 23.

The possibility that "a barren area defining the eastern edge of the coalfield" may be determined by a parallel fold, also pre-Permian in date and Charnian in direction, through East Yorkshire and Lincolnshire, is also thoroughly discussed; and the location of the position of such a fold is one of the main theses of the report cited. From the point of view at that time taken by Prof. Kendall, the location of anticlines as determining boundaries was more important than the lie of the trough-line in the district between, and only by inference do we gather that Prof. Kendall must have suspected that what may be the central trough of the whole coalfield has a Charnian alignment, and that its axis passes through Leeds. The statement by Green,* that the portion of the Coalfield exposed "at the surface has the shape of the half of an elongate basin" . . . "and that it is not unlikely that the other half of the basin lies beneath newer rocks," is admittedly no more than a very shrewd guess, and it is more chance of erosion than anything else that has brought the trough-line, the main Charnian axis, and the outcrop of the base of the Permian to meet near Maltby and to intercross with so small an angle between the general lines of their directions.

In comparing the Barnsley contours of the two main basins as they were in pre-Permian time (Fig. 3) with the arrangement of the contours of the same bed as it is at present (Fig. 2), one notices that the crowding of contours towards the western outcrop of the coal† is no longer a feature which strikes the eye. Crowding of contours about the large basins is, in fact, a resultant effect produced by double tilting in two stages, the one before and the other after the deposition of the Permian, and, in viewing the contours of any coal-seam as it is at the present day in our district, one must always remember that slopes which have a component in the direction 20 degrees north of east have been increased by something like 150 feet per mile; while those which are level, or have a slope with any component in the direction 20 degrees south of west, have been first tilted in the one direction, and then, by a later tilting in a different direction, have had their eastward slope correspondingly reduced. Where, within the central areas of the basins, the measures in

* H.M.G.S. District Memoir *On the Geology of the Yorkshire Coalfield*, by A. H. Green, R. Russell (and others), 1878, page 488.

† *Ibid.*, pages 425 and 428.

pre-Permian times were fairly flat, the dip and strike which they have at present must be approximately identical with that of the Magnesian Limestone; and conversely in the West Yorkshire districts, where block-faulting is the rule, the dip, now inconstant in direction and hardly measureable, must in pre-Permian time have had a general north-westward direction, and have been equal in amount to the present north-easterly dip of the Permian as it is in the district between Pontefract and Selby.

Flanking the main Charnian trough-line on its south-western side, there is some evidence of subsidiary folding parallel to the same direction. In the Yorkshire district these flanking folds are generally wide and shallow, and as most of them lie west of the present line of outcrop of the Barnsley Bed and its equivalents, the writer will leave them for the present, with the remark that they offer an interesting subject for the further application of the method adopted in this paper—taking, instead of the Barnsley Coal, the Whinmoor, Beeston, and Shirtcliffe Seams, some 400 yards lower in the Coal-Measure Series, as being the most extensively exploited, and therefore providing the greatest number of scattered spot-levels available for the drawing of contours in the north-western and western districts.

South of Sheffield, the flanking anticlines are of greater power and amplitude than in the north-western district, and those of Norton—Ridgway—Barlborough—Whitwell and of Holmesfield—Brimington—Tibshelf—Mansfield—Rufford are certainly to be regarded as major features in determining the structure in the Derbyshire and Nottinghamshire part of the coalfield. As the axial line of each of these anticlinal features is continued south-eastwards, it changes its direction; and as the effects of the swells encroach upon the central trough-line of the district, the main line of their trend has curved round until it is approximately east and west. The swan-like shape of the Brimington anticline has already called for comment, and the Norton-Ridgway-Barlborough ridge in pre-Permian time was not dissimilar in form. The anticlines which bring up the Lower Carboniferous rocks in the midst of the Millstone Grit at Ashover, and again at Crich in the midst of the Millstone Grit area further to the south-west, belong to the same family of flanking anticlines and are also parallel to the main Charnian axis of the Pennine Chain.

In order to emphasize and suggest to the eye the not incon-

siderable part played by Charnian movements in determining the lie of all the coalfields about the Pennine Chain, the key-map (Fig. 1, page 414), which shows the area in relation to other coalfields, was prepared in a particular way, each set of formations being ruled over with lines parallel to the direction of their dominant structures. The direction chosen for the lines which indicate the area over which the Carboniferous rocks come to outcrop was obtained by joining Ingleton and Charnwood. This being a paper dealing more particularly with the Sheffield district, this map is herewith presented without comment, and the questions concerning regional structures, more especially the whole question of the structure of the Pennine Chain, which arise out of it, are left to be dealt with on some subsequent occasion.

It needs only a glance at this or at any other map, which brings out the distribution of the coalfields of the South Pennine country, to enable one to appreciate the aptness of the description of the central anticline of the Pennines as breaking up southwards into smaller folds which diverge like the outstretched fingers of a hand, in the hollows between the fingers of which lie the coal-basins of the Southern Midlands.* The eastward bending of the Charnian anticline through Norton, Ridgway, Barlborough, and Whitwell, as also that of Brimington through Tibshelf and Rufford, may be interpreted as the swing of flanking folds, following in sympathetic parallelism the trend of the palmate spreading which marks the structural passage of the main Pennine anticline into the South Midland Coalfield district beneath the Triassic rocks of the Central Midland plain.

As a further suggestion which may throw light upon the causes which produced the eastward curving of the north-west and south-east-ranging folds as they pass into the southern part of the district, one may point out that not far from the southern limits of our area was the great east-and-west ridge of Lower Palæozoic and old rocks, which during almost the whole of the Carboniferous period stood up as land and separated a southern region of South Wales, Bristol, and Belgium from a northern area of deposition, which extended over almost the whole area

* See Maps included in part iii. of the *Final Report of the Royal Commission on Coal Supplies* for District B; see also Lapworth, "Appendix i., Sub-report to the Geological Committee, On the Concealed and Unproved Coalfields in District B," pages 5-17, part ix., Report of the Geological Committee, *Final Report of the Royal Commission on Coal Supplies*, 1905.

and even beyond the limits of the region represented on the key-map (Fig. 1). Against this ridge the Coal-Measures and older Carboniferous rocks thin off, and if the earth-movements producing the compression advanced from the north-east, and gave rise to Charnian folds, the northern district, where the soft and freshly-deposited Carboniferous rocks were thick, might offer less resistance to a given stress, and might therefore be driven forward more rapidly than the resistant old rocks under their thin covering of Carboniferous rocks in the neighbourhood of the ridge on the south. If differential rates of advance were set up at different points along the anticlinal ridges, the effect would be that in the north the waves after a given time would have advanced further south-westwards than in the country to the south, and when the advance was ended, the southern ends of the folds lagging behind would be found to have the eastward bend described above. The effect is, in fact, identical with that of along-shore waves in deep water becoming refracted and advancing into the shallows as breakers with crests parallel to the shore.

In closing the discussion of the effects of Charnian movements, the writer does so with the remark that, except in the immediate neighbourhood of faults which are known to have moved in post-Permian times, the direction of the sline (that is, the trend of the bord-faces of the coal), over the whole area dealt with, does not differ by more than 5 degrees from the main direction of the Charnian trend.*

Of all the pre-Permian features within the area studied—that is, the district east of the Barnsley outcrop—which have a direction essentially different from that of the trough-line of the Charnian, the most notable is the great disturbance along the line of the Don Faults. This ranges north-eastwards and south-westwards, and is therefore almost exactly at right-angles to the Charnian line. As already noted, the displacement along it is generally brought about by a steepening of the dip; but where, as between Rotherham and Sheffield, the disturbance is most narrowly localized, normal faulting and the attendant effects of tensional stress are also in evidence. Comparing the present contours with the pre-Permian contours in the district just south of the Don, but little essential difference is noted. North of

* See *Trans. Inst. M. E.*, 1915, vol. l., page 608; also Prof. P. F. Kendall's contribution to the discussion, *ibid.*, page 612.

the Don, on the other hand, the effects of the post-Permian faulting, which has brought forward the Limestone outcrop south-westwards to Hooton Roberts, have to be discounted, and the pre-Permian contours project north-eastwards about Mexborough to form a *col* with contours which come forward to meet them from the east, and form a lip or spout to the Brierley basin north-west of Doncaster. The pre-Permian effect of the Don Faults is in fact equivalent to that of an anticline with its axis a mile or so north of the line Sheffield—Rotherham—Mexborough—Doncaster, by which the Maltby and the Brierley basins are separated.

South-east of Sheffield begins what is apparently another normal fault through Kiveton Park following the line of the railway to Worksop. Along this line also, when the post-Permian effects have been subtracted, it is found that there remains a displacement which has a considerably more important throw. The line of the Kiveton Fault is here but slightly oblique to the lines of equal thickness of Coal-Measures, and from some points of view it, like the Don Faults, may be regarded as a boundary fault determining not the north-western but the south-western margin of the Maltby Basin. The Kiveton Fault may also be regarded as separating the area under discussion into (1) a Yorkshire region, where the presence of wide open basins is the characteristic of the tectonic structure, from (2) a Derbyshire and Nottinghamshire region, in which the subsidiary flanking anticlines of the Pennines play a considerably more important part.

There remains the West Yorkshire region of block-faulting. In West Yorkshire the direction of the major faults, as mapped by the Geological Survey and described by Green, seems to be north-east and south-west, and therefore generally parallel to the line of the Don Faults. Experience gained by mining goes to show that these and the complementary faults which break the north-westerly and south-easterly-ranging strips into blocks, and not infrequently traverse two or three of the strips together without discontinuity of line, are all of the type of normal faults, and are therefore probably due to stretching. In visiting a considerable number of pits and in examining the plans of their workings in this block-faulted area, the writer has always had it in mind that some day or other he will meet with evidence which will determine whether the north-eastward-ranging faults

cut, or are cut by, the north-westerly faults. Up to the present in no single case has he been able to obtain a conclusive answer. and though he has examined a great many cases of faults anastomosing and afterwards branching, and though many examples of faults changing either or both their direction and their throw are known to him, he has seen no evidence which does other than suggest that the whole system of faulting was accomplished as part and parcel of one and the same earth-movement, which he thinks of as belonging to the tensional period which followed upon the release of pre-Permian Charnian stress. The statistical evidence of the map, that spot-levels obtained from many scattered pits in the midst of the fault-block structure give contours which are neither crooked nor irregularly spaced, is strongly in favour of the same conclusion.

The evidence that will give the answer to the question of the time-relationship between the Charnian folding and the great Pendle fold, which cuts off both the Yorkshire and the Lancashire coalfields along a latitude north of Leeds, comes mostly from a region beyond the northern boundary of the map (Plate VII.); and only remarking that, in the district from Wakefield northwards, extensional faults (normal faults with very flat hade) ranging more nearly east and west seem frequently to break away from the main north-easterly faults, and putting forward the suggestion that when block-faulting was in progress the region was resting against, and tending to slip or fall away from, a Pendle ridge the central axis of which lay some few miles further northwards, and which was no longer supported by the earth-pressures which had caused its uplift, the writer will not at present pursue the subject.

Concerning the faulting which accompanies the anticlines and troughs of the southern district, the writer cannot do better than quote from Gibson, who states* that "the close association of faulting and folding as exemplified by the faults accompanying the Brimington anticline is repeated in several other cases"; and with a final *cave*, also from Gibson, that "it is perhaps too generally assumed that the concealed coalfield was even less influenced by the pre-Permian movements than the visible coalfield," the writer may conclude this section of the paper.

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* H.M.G.S. District Memoir *On the Geology of the Concealed Coalfield of Yorkshire and Nottinghamshire*, page 40.

The PRESIDENT (Mr. C. C. Ellison) proposed a hearty vote of thanks to the author for his paper, and the resolution was cordially adopted.

Mr. ARNOLD LUPTON (London) said that it was 45 years since he had drawn a map of the coalfield from Leeds to Nottingham, showing all the outcrops, and embodying all the information that he could obtain from geologists and government maps and from his own explorations. In another 45 years another paper on the coalfield would tell them a great deal that they did not know at the present day. Prof. Fearnsides had referred to the depression of the coalfield that took place during the laying-down of the successive beds of rock and coal, so that they got the total thickness of 5,000 feet of Coal-Measures deposited in succession. What was the cause of this continual subsidence? Was it the weight of the strata deposited? He would like to ask how far volcanic action had any effect in withdrawing support from the surface.* With reference to the first part of Prof. Fearnsides's paper,† the author had given on page 579 an account of an interesting discovery by Dr. Clifton Sorby as to the amount of water that was mixed up with and remained in the mud until an enormous pressure was brought to bear upon it, which drove the water away. That was put as a weight of 1,250 *tons* per square inch. He (Mr. Lupton) suggested that this was a clerical error for *pounds* per square inch. Dr. Sorby had stated that, taking the specific gravity of the ground at 2·5, this would mean a depth of 2,700 feet. He (Mr. Lupton) accepted the gravity as 2·5, but he thought that it would mean a depth of about 1,350 feet, and that at that depth they would have a pressure sufficient to drive out the water. He should like to know how that water got away. Of course the expulsion of the water was not done in a hurry—it went very gently—but still they knew that the form of a great deal of the Coal-Measures, as they were to-day, would resist a great pressure of water without its escaping. What he wanted to know was whether that water came away through fault-slips, or through cracks in the strata, or came so slowly that it gradually percolated through some microscopic pores in the beds.

* The continued ejection of gases from the wide crater of a volcano must in course of time remove a great deal of the solid ground.—A. L.

† *Trans. Inst. M. E.*, 1915, vol. l., page 573.

Prof. P. F. KENDALL (University of Leeds) said that it was difficult to criticize the paper without first having time in which to digest the mass of information that it contained. He felt reluctant therefore to enter into details, because he did not want to make premature or imperfect disclosure of any work upon which he was himself engaged. The contour method was one which had been applied in many areas. Prof. Lupton many years ago had attempted to project a plane of the base of the Permian rocks forward to the westward up into the air, as Prof. Fearnsides had done with a considerable amount of success. That, he thought, was an exercise perhaps less hazardous than projecting it forward to the east. The amount of information available with regard to the Permian rocks east of the outcrops was exceedingly small—some dozen or two boreholes and shafts—and these displayed discrepancies which he was afraid would scarcely justify the regularity of the lines that had been drawn. Indeed, where Prof. Fearnsides's lines extended from the known region to the unknown, they became more generalized. When anyone began to generalize, as the information declined the generalization enlarged. They had singularly little evidence of the steady and regular increase of the Permian rocks to the northward. There were two or three boreholes in the Selby area, and then a vast hiatus from there to the mouth of the Tees. He did not think that one would be justified in projecting contour-lines over the great intervening area of perhaps 60 or 70 miles upon such imperfect information as that. He must feel a certain degree of personal gratification to find that rather bold speculations and generalizations of his own had been sustained in some measure by Prof. Fearnsides's work. There might be some in that room who had seen a copy of a very small-scale map that he had ventured to put before the Royal Commission on Coal Supplies, embodying his views as to the probable (or possible) extension of the concealed coalfield. That portion of the map which was extended in a south-easterly direction into the Fen country was rather severely criticized by members of the Geological Survey at the time, and a member of the Royal Commission attached to it a name which, he was sorry to say, still lingered in the minds of members of the Commission, and was occasionally quoted—namely, "Kendall's preposterous belly." That extension of the coalfield was, he thought, con-

siderably sustained and justified by the work that Prof. Fearnsides had done. Prof. Fearnsides had accepted the Charnian ridge—a very complex ridge of ancient rocks extending from Charnwood (Leicestershire), with a general north-west and south-east direction. He (the speaker) suggested that that furnished a line which would be approximately parallel to the boundary of the coalfield in that direction, and Prof. Fearnsides's work seemed certainly to justify it to that extent. When one came to consider the contouring of the Barnsley Bed, it was very ingeniously worked out, and in its main lines he should be disposed to agree with it; but he had yet to consider, from the data now put into his hands, whether the faults could be ignored. He imagined that they could not be ignored. Prof. Hull had, many years ago, endeavoured to analyse two sets of movements —one set of north-east and south-west foldings (the Pendle direction), and another (the Pennine) intersecting north and south, with a related fold running east and west. He (Prof. Kendall) had endeavoured to trace the order of succession of the movements that produced these two sets of folds. In considering the course of the northern limit of the coalfield—upon which, it was evident, Prof. Fearnsides and himself would not entirely agree —he had looked into this question rather carefully, and he found that the actual termination of the Yorkshire coalfield on the north was partly by outcrop and partly by a great master fault. That fault obeyed the law—or rather followed an average of behaviour—which was common to very many of the great faults of this coalfield, namely, it had an increase of throw in the easterly direction. The boundary-fault, where it formed a definite boundary of the coalfield, commenced with a small throw on the west, and with a greatly increasing throw towards the east. As it was traced eastwards, its throw was found to increase very considerably, and this was most significant as bearing upon the question of dip. If they had a great fracture in one direction, and then another system of fractures that tended to intersect it, the earlier fault would end off the later ones, which would simply run against it and make no further progress. It was just as if a window had been cracked: any subsequent cracks would run against the first, and not cross over it. He found that the north-west and south-east faults did, so far as information was available, run up against that east-and-west fault, whence he con-

cluded that the east-and-west faulting was prior to the south-west and north-east faults. Everyone knew that enormous fractures existed in the south-west and north-east direction. These had a bearing, too, upon the question of the further extension of the coalfield to the north, and he had that in mind when he ventured to draw up a small-scale map. He did not want to be taken too literally and exactly. Dr. Walcot Gibson had applied a clinometer to an imaginary section crossing his (the speaker's) assumed barrier, and had pointed out that the Selby borehole disclosed a probable thickness of Coal-Measures that could not be eliminated along his line unless a rather considerable dip were imported. But Dr. Gibson, in that case, had quite omitted to take account of this great fault. The fault did extend under the Permian rocks, and therefore they might have a considerable depth of Coal-Measures on the south side, and none at all on the north, which was actually the case.

He (Prof. Kendall) had listened to the paper with very great interest. He would study it with careful attention, and he hoped that it was merely the first of a series of papers of that type. The method, as he had said, had been employed previously. Mr. Cosmo Johns employed a somewhat analogous method—although, being a very busy man, he was unable to apply it in such detail as Prof. Fearnsides had done—to the consideration of contemporary movements during the deposition of the coal. He (Prof. Kendall) had also applied the method, and had solved a rather knotty problem in regard to one of their very important seams in the northern part of the field, and in due time he would produce his results.

Mr. LUPTON asked how it was that the depression took place, suggesting that it was by weight. He should also like to ask how the elevations took place. Prof. Joly, of Dublin, had stated that the elevations took place in consequence of the radium that was in the soil, and that the mighty Himalayas had been raised to their height of 30,000 feet by that action!

PROF. W. G. FEARNSIDES (Sheffield University), in reply, said that the work of assembling the facts put on record in his paper had proved a very congenial and stimulating task. The very circumstance that, in order to plot the pit-sites, he had to visit so many collieries, distributed over the length and

breadth of so large a district, had given him an insight into many matters connected with coalfield geology which he might otherwise never have had the opportunity to see.

He was sorry that he could give no authoritative answer to Mr. Lupton's questions as to the ultimate causes which have produced earth-movement and vulcanism. He might, however, refer Mr. Lupton to the writings of the illustrious Lyell, who found sufficient explanation in the application of the Laplacian doctrine of a cooling earth, which explanation might still fairly be said to hold the field. Alternatively, he might also refer him to the works of Chamberlin and other American writers of the present day, who thought of the earth as continuing to grow by the segregation of "planetismals," and as rising in temperature and developing internal energy and heat through gravity the while it grew. Mr. Lupton had made mention of the views held by certain people who had made experiments with radium. To the speaker, when reading the writings of radiologists, had come a suspicion that some of those who had done much to advance our knowledge of radio-activity in the laboratory, and had passed on to make computations of radio-active effects within the crust of the earth, had carried their deductions beyond a logical conclusion. In any case, the whole matter would be better left to be settled by the cosmic physicists and astronomers than dealt with by a geologist, whose chief aim was to assemble evidence and to put on record facts concerning earth-movements which others might be able to explain.

He thanked Mr. Lupton for drawing attention to the curious misprint which had crept in on page 579 of Part I. of the paper. The "1,250 tons" which Mr. Lupton had argued upon should have been 1·250 tons (1¼ tons). The number was taken from Dr. Sorby's paper, and the final nought, which perhaps it would have been better not to transcribe, was required for uniformity in the table as printed.* Except for the comma in place of a decimal point, he had not been able to discover any arithmetical error in the calculation as given.

The water which was expressed from the mud as originally deposited probably made its way quite slowly through devious crannies and along capillary tubes between the individual

* *Quart. Journ. Geol. Soc.*, 1907-1908, vol. lxiv., page 231.

particles which composed the rocks, from regions of high pressure to regions where the pressure was less. The expulsion of the water was probably finally completed before the rocks were affected by jointing, or by any sort of faulting, cracking, or slipping movement.

He thanked Prof. Kendall for his kindly and generous appreciation of the paper. He could not quite agree with Prof. Kendall's remark that he (the speaker) had "accepted" the Charnian ridge. What he had done was to plot the contours, and as soon as ever the form of the contour-lines of the pre-Permian surface of the Barnsley Bed was revealed, it became evident that structural features with north-east and south-west elongation were dominant over the whole coalfield, and that, therefore, Prof. Kendall's view that the coalfield lay in a hollow between parallel Charnian ridges was the only hypothesis which was in accordance with the facts.

With respect to the hazard of continuing the contour-lines to show the geometry of the base of the Permian from Selby northwards towards the mouth of the Tees, the speaker could quite agree with what Prof. Kendall had said. He would, however, remark that the area proved by boring to be of average regularity extended some considerable distance to the north-east of Selby,* and the sites of at least three boreholes in the district east of Selby were within 4 miles of the northern edge of the district shown upon the map. The unproved triangle, with Selby, Askern, and Peckfield as its apices, was certainly a large one, but he did not think that any of the contours shown for the Coal-Measure surface beneath the Permian had been exterpolated on insufficient evidence.

Prof. Kendall had raised the question whether, in plotting the contours, for the purpose of expressing the geometry of folded strata over a considerable area, it was reasonable altogether to ignore the effects of faulting. In so doing, he had reopened a very important aspect of the case. The matter was discussed at some length at a meeting of the Geological Section of the British Association at Manchester in September, 1915,† and the general consensus of opinion then expressed was that

* See H.M.G.S. Memoir *On the Thicknesses of Strata in the Counties of England and Wales*, 1916, page 152.

† 1916, *Report of the Eighty-fifth Meeting of the British Association for the Advancement of Science, Manchester, 1915*, page 425.

to ignore acute and localized disturbances which belonged to faulting was to make an assumption which could only be justified by results. A reference to the general parallelism and even sweep of the sinuous contour-lines of the Barnsley Bed over the whole area between Wakefield and Mansfield was the best answer which the speaker could make, and he thought that Figs. 2 and 3 (Plate VIII.) and the ½-inch map as presented in illustration of the present paper (Plate VII.) were a fairly complete justification of the assumption which he had made. He had thought about the matter a good deal, and he quite realized that when contours were drawn at small vertical intervals over an area which was represented on a large-scale map, it was essential that the direction, the hade, and the throw of the faults should be considered. Nevertheless, he had concluded that over broader areas by employing series of contours, the vertical interval between successive members of which was not small as compared with the average throw of the faults, a purely geometrical consideration of the available spot-levels provided by the various pits and boreholes could be made to yield useful generalizations.

He should be exceedingly grateful if Prof. Kendall could take the matter up. He (Prof. Fearnsides) hoped in course of time to present for discussion a map of a portion of the area now dealt with, contoured with vertical intervals smaller than the 100 yards adopted for the present map, and properly corrected for all the faulting which had been proved by mining; but that would be a task that would require both time and the co-operation of the mining engineers engaged in the winning of the minerals in the areas dealt with. He had regarded the preparation of the present map as the best means of improving his own education with regard to the general conformation of the coal-field as a whole, and he thought that the broad survey which it presented might prove of value when, by means of contoured maps or plans of larger scale, the structure of particular portions of the area was being compared with the structure of neighbouring districts. He thought, also, that the map might serve well to indicate what portions of the area should first be selected for geometrical investigation on the more detailed scale.

# THE MIDLAND COUNTIES INSTITUTION OF ENGINEERS.

GENERAL MEETING,
HELD AT THE UNIVERSITY COLLEGE, NOTTINGHAM,
MAY 6TH, 1916.

MR. G. S. BRAGGE, PRESIDENT, IN THE CHAIR.

Mr. PERCY W. LEWIS (Acting Secretary) announced the election of the following new members:—

MEMBERS—

Mr. FRANCIS GLYNNE WHELER, Mining Engineer, Calton House, Camborne, Cornwall.

Mr. HARRY STEPHEN LAND, Mechanical Engineer, 75, Old Road, Lee, London, S.E.

STUDENT—

Mr. HENRY JOHNSON MEIN, Mining Student, Farnsfield, Southwell, Notts.

## DISCUSSION OF MR. C. DICKINSON'S PAPER ENTITLED "DESCRIPTION OF WATER-DAMS IN COAL AT NETHERSEAL COLLIERY."*

The PRESIDENT (Mr. G. S. Bragge) said that Mr. Dickinson had told them previously that the dams were first of all in a semi-fluid state, and that as they consolidated they became better. Had time proved that they were continuing good?

Mr. C. DICKINSON (Netherseal Colliery) said that, owing to the stowing-up of the headings leading to the dams for a distance of 50 to 100 yards, one was unable to get near to them. There had, however, been no signs of leakage, and consequently he presumed that the dams were still intact. The district was now abandoned.

Mr. W. H. HEPPLEWHITE (H.M. Inspector of Mines, Tamworth) said that he had seen the dams, and in his opinion they

* *Trans. Inst. M. E.*, 1914, vol. xlviii., page 400; and 1915, vol. xlix., page 459.

were a most magnificent piece of work. Would Mr. Dickinson inform them what had been done with regard to the boring of holes and forcing in of cement into the coal?

Mr. DICKINSON said that three other dams had been put in in another part of the workings; they were fortunate in having three headings in which to do the work, and two of them were in the coal. In one of the headings, which had been driven 20 years before, the roof had fallen in 4½ feet, and consequently the heading was filled with loose *débris*. They had to go 4 feet below the bottom, and when finished some of the dams were as much as 14 feet high. They got in 7 feet on each side, and the total width was 24 feet. They bored in 12 feet on each side of the ordinary heading with the ordinary workman's boring apparatus, and forced in a mixture of cement and water. In one of the holes (which was only 1¾ inches in diameter) as much as 25 cwt. of cement was inserted. The coal was 9 feet thick.

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## DISCUSSION OF MR. JAMES BLACK'S PAPER ON "FORMING A SHAFT-PILLAR IN THIN SEAMS."*

The PRESIDENT (Mr. G. S. Bragge) said that Mr. Black had advocated the use of longwall places for forming the pillar instead of headings. Why not go farther, and do away with a shaft-pillar altogether, as had been advocated by the late Mr. W. H. Pickering?†

Mr. W. H. HEPPLEWHITE (H.M. Inspector of Mines, Tamworth) said that the proposal was more for ventilation purposes. Mr. Black did not say what leakage he would get through the pack-walls. His (Mr. Hepplewhite's) experience was that it was difficult in such cases to convey the ventilation to the face, owing to the leakage through and over the packs.

Mr. G. J. BINNS (Duffield) said that he imagined that in the system to which reference had been made they had an intake and a return without two headings.

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* *Trans. Inst. M. E.*, 1915, vol. l., page 449; and 1916, vol. li., pages 166 and 292.

† *Ibid.*, 1912, vol. xliii., page 428.

## DISCUSSION OF MR. SAMUEL DEAN'S PAPER ON "MODERN AMERICAN COAL-MINING METHODS, WITH SOME COMPARISONS."*

Mr. C. DICKINSON (Netherseal Colliery) said that the idea suggested in the paper seemed to be to take the railway-wagons down the pit and fill them there.

The PRESIDENT (Mr. G. S. Bragge) said that he was struck with the large size of the trams; that might be owing to certain physical advantages which they had in America. The question that might arise in regard to the size of the trams was how, in the event of one getting off the road, they would get it back again.

Mr. WILLIAM H. LEWIS (Derby) said that South-Welsh coal-trams, although large, were quite easily dealt with; he had seen a man lift, unaided, one of these trams back on to the rails. This was due to the leverage obtained by their length, which was generally 6 feet overall; also to the large wheels (about 16 inches in diameter), and the closeness of the axle centres. The trams were built of steel throughout, the tare being 10 cwts. and the capacity 30 to 40 cwts. When lifting the tram, the man put his back against it, and generally wore a leather back-pad.

The PRESIDENT said that the trams were very well built; they had axles almost like those on a railway-wagon, and it seemed to him that as they were a more perfect piece of machinery than the trams in this country, there was not the same liability to get off the road so frequently.

Mr. W. H. HEPPLEWHITE (H.M. Inspector of Mines, Tamworth) said that, as the trams ran on springs and had ball-bearings, they were actually better than railway-wagons. They must, however, have very strong floors and well-laid rail-tracks on which to run. Other remarkable points mentioned in the paper were the coal-cutting machines and the overhead trolleys. In some cases the wires were almost close on to the workmen, and apparently a movable covering of wood was used and shifted along the wires in order to prevent the men from coming into

* *Trans. Inst. M. E.*, 1915, vol. l., pages 179 and 388; and 1916, vol. li., pages 35, 340, and 386.

contact with the live wire. Fig. 31 showed a cutter working with a 10-foot cutter jib, and it would be observed that there was not the slightest bit of timber supports. It was stated on page 194 that the number of fillers following the cutters was restricted by trade-union regulations, which showed how progress was retarded by trade-unionism in the United States. The machines, however, were really remarkable pieces of workmanship, and holed either a yard above the floor or a yard below, as well as in the middle of the seam. Fig. 45 (page 203) showed a cutter and header at work; the cut coal dropped into a conveyor, and was taken away without being handled. The roofs must, however, be extraordinarily strong, as there were no timber supports. The prevalent conditions must be very favourable for the machine, otherwise it would not work; in fact, he knew of no mine in England where undercutting to a depth of anything like 10 feet would be allowed.

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## DISCUSSION ON FUEL ECONOMY.

Mr. E. Bramall (Leicester) said that at all collieries where there was much water to be pumped, the quantity remained about the same. Pumping, in many cases, required nearly as much fuel as coal-winding, and in view of the decreased output from the mine, instead of a reduction in the percentage of coal consumed, he thought that there would be an increase.

The President (Mr. G. S. Bragge) said that at old collieries there were many small engines scattered about, each with its own range of steam-pipes. It was a question whether it would not be beneficial to do away with these probably wasteful engines and to centralize the power required.

Mr. Bramall said that they could not centralize the power with steam-engines. The only solution for the reduction of the consumption where power in small units was required in many places was to utilize the exhaust-steam from the winding and other large engines by turning it into electricity by means of an exhaust-steam turbine. That, however, could only be done at the present time by those who were already prepared, as electrical machinery could not now be obtained. He had had Meldrum

furnaces fitted to a number of boilers, but the result had not been successful. The quantity of steam had not increased, and, if anything, the consumption of fuel had gone up.

The PRESIDENT said that when they had fuel of varying sizes, which rendered it unsuitable for the automatic furnaces, it had to be broken up to a uniform size. Sometimes big lumps which were not quite good enough to go into the sales were put into the firehole. In 1873, when the price of coal was so very high, it was sometimes found advisable to stoke with the best coal. When the prices of slack and big coal were very wide apart, they naturally turned to slack; but when the price of slack went up, they used the large coal, and there was even economy in that. In those days slack itself was found to be more valuable for turning into coke than burning under the boilers.

Mr. W. GATH WATKINS (Derby) regretted that nothing good had been said by the previous speakers about mechanical stoking equipment as applied to colliery plant. These machines were adopted in all up-to-date steam-plants and in power-stations where the utmost economy was considered of importance. In making a comparison of the performances of steam-plant, care should be exercised in collecting the data for comparison, and the following points must be taken into consideration:—

(1) The type of the boiler.

(2) The size and rating of the boiler capacity.

(3) The calorific value and physical quality of the coal used, and the quantity burnt in unit time.

(4) The temperature and quantity of feed-water evaporated in unit time.

(5) The grate area.

(6) The temperature of gases in the flue at the rear of the boiler.

(7) The percentage of carbon dioxide in the flue-gases.

One of the speaker's experiences was with a steam-plant, consisting of a well-known type of water-tube boiler and high-speed engine for generating electricity. The above points were investigated, and the efficiency of the plant was greatly improved after the area of the grates and the methods of hand-firing had been adjusted. The improved results showed a larger percentage of carbon dioxide in the flue-gases, and the temperature of the

latter was reduced from 500° and more to 350° Fahr. Less fuel was burnt, and the number of pounds of water evaporated per pound of coal was increased. A permanent carbon-dioxide recorder was installed, and the fireman received a bonus on the percentage recorded. Permanent arrangements were made for measuring the feed-water and coal, the quality of coal being colliery smudge.

With regard to the performances of well-known makes and types of boilers, he believed that there was very little difference in their performances if properly used, and if allowed the same chance and worked under the same conditions, they would probably yield the same amount of steam for the amount of coal burnt.

Mr. Bramall said that they could not set out to burn only one class of coal at collieries, but had to use any fuel that could not be put on the market. On the other hand, at electricity and similar works they could select their fuel: they burned breeze or some other graded fuel which was of an even size, and this could be dealt with mechanically. They could not deal mechanically with the very mixed fuel that had to be used at collieries.

# THE INSTITUTION OF MINING ENGINEERS.

GENERAL MEETING,
HELD IN THE ROOMS OF THE GEOLOGICAL SOCIETY, BURLINGTON HOUSE, PICCADILLY, LONDON, W., JUNE 8TH, 1916.

SIR WILLIAM GARFORTH, PAST-PRESIDENT, IN THE CHAIR.

## CHAIRMAN'S OPENING ADDRESS.

The CHAIRMAN said that he had much pleasure in announcing that the Council at its meeting that morning had accepted the recommendation of the General Purposes Committee, and had unanimously nominated Mr. Wallace Thorneycroft as President of the Institution for the ensuing year, and that Mr. Thorneycroft would be duly elected at the meeting to be held in Glasgow in September next.

It gave him equal pleasure to state that the Council had accepted the recommendation of the Medals Committee, and had awarded the Institution Medal to Dr. William Atkinson, I.S.O., H.M. Divisional Inspector of Mines, and a Past-President of the Institution, whose specially valuable work was well known to the mining profession.

As the members were aware from the announcement made in the General Meeting circular, the new Bye-laws enacted under the Charter of the Institution had been allowed by the Lords of the Privy Council, and had come into operation on January 12th, 1916. The Bye-laws had received the most careful consideration from the special committee appointed to draft them, and had been approved by the Councils of the various Federated Institutes. The Council considered that the embodiment of these Bye-laws in the Charter would, with the qualifications now required for membership, tend to raise the status of the Institution.

On behalf of the Council, he desired to express how sincerely and heartily they all wished their late President, Sir Thomas

Holland, every success as Chairman of the Commission that had been appointed to carry out important duties on behalf of the Home Government and the India Council. As a Fellow of the Royal Society, a Fellow of the Geological Society, and a member of other kindred Institutes, Sir Thomas Holland's association with the Institution was greatly valued by all the members. He (Sir William) wished on behalf of the Council to take this opportunity of thanking Sir Thomas for the very able and efficient manner in which he had conducted its affairs during his Presidency.

He was glad to announce that, with the approval of the Advisory Council for Scientific and Industrial Research, the Council of the Institution had appointed Mr. Wallace Thorneycroft (the President-Elect) to the vacancy on the new Committee on Coal Mining caused by the resignation of Sir Thomas Holland. He now desired to draw the attention of the members to a communication which had been received from the Advisory Council, which consisted of the Lord President of the Council (Lord Crewe), the Chancellor of the Exchequer, the Secretary for Scotland, the President of the Board of Trade, the President of the Board of Education, Lord Haldane, the Right Hon. A. H. D. Acland, the Right Hon. Joseph Pease, and the Right Hon. Bonar Law. This Committee of the Privy Council made grants on the advice of a small Advisory Council composed of eminent scientists and men actually engaged in industries dependent upon scientific research. The members of the Advisory Council were Lord Rayleigh, Sir George Beilby, Mr. W. Duddell, Prof. J. A. McClelland, Sir Charles Parsons, Prof. J. F. Thorpe, and Mr. R. Threlfall, with Sir William McCormick as Administrative Chairman. This Advisory Council was not and could not very well be made representative of all the great industries of the country without unduly increasing its size. The difficulty of securing adequate representation had been met by the establishment of strong standing committees concerned with the most important industries. The main function of these committees was to advise the Council on researches relating to the industries with which the standing committees were concerned. Accompanying the communication was a request for this Institution to nominate four representatives to form part of a committee on mining, the first members of which were Sir Thomas Holland,

Dr. J. S. Haldane, Dr. Robert Moore, and himself. Other institutions were invited to nominate members to this committee, and a certain number of members were appointed directly by the Advisory Council. The committee was organized in two sections, one dealing with the mining of iron, coal, and hydrocarbons, and the other with the mining of minerals other than the foregoing. The first meeting of this committee was held at the offices of the Board of Education on May 9th, 1916, and in the afternoon of the same day separate meetings of the two sections were held also. It was arranged that the committee should enlist the services of a certain number of members of this Institution who had special knowledge and experience in those branches of the industry in which they were especially competent to assist in the proposed scientific and industrial enquiry. Having regard to the valuable papers which the members of this Institution had already contributed to the *Transactions*, in which was indicated the present method of winning and presenting coal in the best commercial condition, he (Sir William) felt sure that every member of it would at this crisis in our history wish to comply with the requests of the country's trusted advisers. Time would not permit him to enter into details of the various subjects suggested, but it was considered necessary to mention some of the lines on which the investigation might proceed.

It could be shown that the general practice of British coal-mining was quite equal, if not superior, to that of any other nation with regard to the tonnage produced per life lost, the quantity of coal obtained per foot per acre, and the low cost of underground production, considering the high wages paid to the workmen, and the utilization to the best advantage of the great forces of Nature. These results were principally due to the long-wall method of working coal-seams, which it had taken British mining engineers many generations to perfect, after selecting the best points from other systems of working that had been carried out in this country for centuries. This method had lent itself admirably to the introduction of coal-cutting machines, by which rapid advance of the coal-face was obtained, and the coal was subjected for the shortest possible time to the superincumbent weight. The straight undercut induced a straight line of break, so that the roof was maintained in a more solid and unbroken condition, which advantage, assisted by the straight line of

timbering, had been the means of reducing the number of accidents from falls of roof. Statistics showed that in some mines worked by these methods no fatal accident had occurred at the coal-face during the past 20 years, in which time several million tons of coal had been got. The straight line of face had opened the way to the coal-face conveyor, and this introduction of mechanical means had further increased the output of coal per man per day. Owing to the more regular subsidence, the result was a more uniform settlement of the overlying seams and surface land, with beneficial results. These advantages had in recent years become more apparent in the working of deep mines, and as the natural temperature increased the method would be found to assist the ventilation and lead to other advantages. Whilst the longwall method was not applicable to all mines, many seams, some of them thin and lying at a considerable depth, were now being profitably worked by this system, to which at one time objection was made. Full advantage had not yet been taken of labour-saving appliances, owing in some instances to the irregular line of face. Experience gained during recent years had shown that the output could be increased materially by many different appliances. As there might be a scarcity of labour, possibly due to the number of men lost in the present war, all means must be taken to make up the difference by giving the men the benefit of every mechanical appliance in order to obtain the maximum output.

With regard to the consumption of coal for raising steam, it might be pointed out that in certain manufactories in this country great economy was obtained from working the boilers at a pressure of 150 to 180 pounds per square inch, with softened feed-water heated to over 300° Fahr., by economizers, and by having the surface of boilers and economizers suitably proportioned to the load; with careful firing a resultant thermal efficiency of 70 to 75 per cent. was obtained; further, by the use of superheaters and a compact arrangement of plant, with short ranges of steam-pipes well covered with non-conducting material, and by using the steam in turbines or in modern well-designed compound-condensing engines, a steam-consumption of only 10 to 12 pounds was being obtained per indicated horsepower-hour, or the exhaust-steam from the main engines was used to

drive turbo-generators for supplying current to isolated auxiliaries. Whilst these beneficial results were being obtained in some textile and other industries, the steam plants at many collieries were most wasteful. For instance, with a steam pressure of 60 to 70 pounds, boilers improperly covered, imperfect boiler-settings, allowing large cold air-leakages, hard water forming thick scale, no economizers or feed heaters, boilers hard-fired with deficient heating surface, or lightly fired with excessive heating surface, also careless firing, the result was a thermal efficiency of less than 50 per cent. The steam, after passing through long ranges of insufficiently covered pipes, was often used in non-expansive non-condensing engines, the result being a steam-consumption of 50 to 100 pounds per indicated horsepower-hour.

Another most important part of the investigation was to enquire into the national loss entailed by neglect to recover more of the valuable substances of which coal is composed. It was hardly necessary to remind the members of the Institution that coal was the raw material from which, in the production of coke, ammonia, tar, and benzol were obtained, that ammonia when converted into sulphate was most valuable to agriculture as a fertilizer. In other forms it was needed by the woollen and calico industries, for the manufacture of permitted explosives, as the refrigerating medium by which cold storage was made possible, and it was also largely used in the chemical, electrical, and other trades. Tar, with its hundreds of derivatives, was essential to the dyeing industry, for the production of high explosives, to the medical and surgical professions for drugs and antiseptics, to the rubber and photographic industries for solvents and developers, in addition to being required in the raw state for road-making, felt-making, etc. Benzol, besides furnishing an additional supply of raw material for the above purposes, was also used as a fuel in internal-combustion engines, and furnished refined products which were required for purposes similar to those for which the tar derivatives were used. Although the distillates of coal were essential to many industries, only about 20 per cent. of the output of this country was at present carbonized, and the whole of the tar, ammonia and benzol contained in the remaining 80 per cent. was therefore lost. The reason for this was presumably that the colliery companies had

been able to find a more profitable market for their coal without erecting coke-ovens, or old colliery concerns might have exhausted their good seams, and the remaining seams were of too poor quality to warrant a large expenditure of money in recovery plant. But the time had now arrived when coal should no longer be regarded simply as a fuel, and every member of the Institution ought to be conscious that the nation should get the greatest possible value out of the coal he was producing. It might be mentioned that of the quantity carbonized, 5,000,000 tons a year were being burnt in bee-hive ovens, without obtaining the recovery of the bye-products. This quantity alone represented a loss to the nation of 70,000 tons of ammonium sulphate, 250,000 tons of tar, and 12,000,000 to 15,000,000 gallons of benzol, all of which could be saved if the coal were distilled in retort ovens. In connexion with the distillation of coal, enquiry should be made into the possibility of utilizing the waste gases from bye-product ovens, as there were at the present time 7,000 million cubic feet of waste gas available annually, of which only a small proportion was being utilized. It might be mentioned that power schemes had been worked out with much success in some districts of the country where the waste gases from coke-ovens and furnaces were collected and utilized. There was still ample scope for neighbouring collieries, steel-works, and public lighting and power companies to co-operate, and thus save the continued waste of this cheap source of power.

Amongst other sources of waste, it might be pointed out that large areas of coal had often been left in consequence of spontaneous combustion, and the fear of loss of life. Pillars of coal had likewise been left as boundaries between estates, which waste it was hoped would in future be avoided. Large pillars of coal had also been left for the support of reservoirs, railways, and other structures on the surface, where the injury and cost of repairs had been insignificant compared with the value of the coal left. It was to be hoped that some Government interference would take place so as to prevent similar pillars from being left in working the deep mines of the future.

It was impossible in the time at his disposal to enumerate other details which related to the proposed investigation required by the Advisory Council. He might, however, express the hope

that, by a more intimate interchange of ideas between the Advisory Council, members of the Royal and other scientific societies, the Institution of Mining Engineers, and the representatives of the various industries not only in this country but in our Colonies, advantages would be gained which hitherto, for want of such combination, had not been possible. He felt sure that every member of the Institution would be anxious to respond to the appeal of the Advisory Council, and give of his best for the sake of his country. Besides having regard to the "trade war" which would follow the conflict that was now raging, we might expect that the time would come when the brave members of the Institution who were now at the front would return and enquire what those who had been at home had done, and we might then point to the scientific investigations that he (Sir William) had mentioned, which, it was believed, would be the means of enabling the Empire to maintain its position amongst the powerful nations of the world. What was required at the present time was a serious attempt to utilize to the fullest extent the best of every method and appliance in this country, and to abandon as soon as possible all that might be defective and detrimental. The commercial success of a country depended on a cheap supply of fuel, which might be said to constitute the foundation on which all other industries rested.

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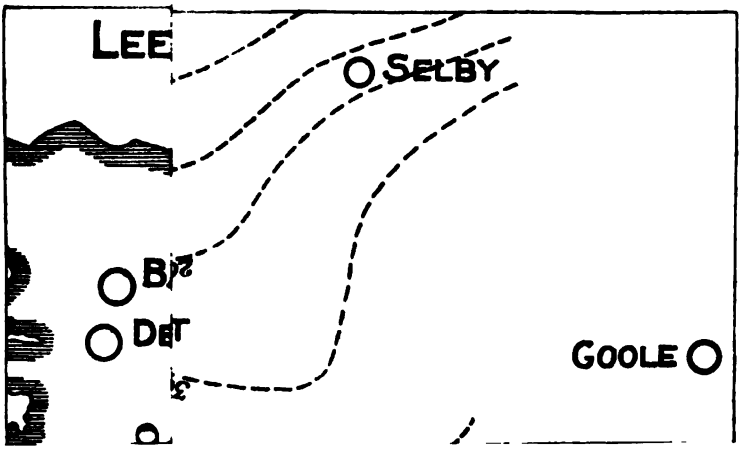
Dr. J. S. HALDANE read the following paper on "The Health of Old Colliers":—

*District (South Yo Derbyshire, and Nottinghamshire)."—Part II.*

HE BARNSLEY BED.



# THE HEALTH OF OLD COLLIERS.

By J. S. HALDANE, M.D., F.R.S., Director, Doncaster Coal-owners Research Laboratory.

Every ten years there is published an invaluable Supplement to the Registrar-General's Reports, in which the annual mortality in different occupations is set out and discussed generally, so that the relative healthiness of these occupations can be definitely gauged.

It was shown in the last Supplement, in connexion with the census of 1901, that the general death-rate among colliers was considerably lower than in the great majority of occupations. But there is an exception to this in the case of colliers above the age of 55. These points are shown in Table I., in which are also incorporated the earliest available official figures—those given in evidence before the Royal Commission on Mines that reported in 1864.

Table I.—Death-rates per 1,000 living at each Age-period.

| Age-period. | | 15-25. | 25-35. | 35-45. | 45-55. | 55-65. | Over 65. |
|---|---|---|---|---|---|---|---|
| 1849-1853 | All males, England and Wales ... ... ... | 8·1 | 10·1 | 12·7 | 18·9 | 31·8 | — |
| | Coal-miners (mean for Staffordshire, South Wales, and Northumberland and Durham) | 14·5 | 14·5 | 17·2 | 26·3 | 44·0 | — |
| 1900-1902 | Occupied and retired males, England and Wales ... ... ... | 3·5 | 6·3 | 10·9 | 18·7 | 35·6 | 106·0 |
| | Occupied and retired coal-miners, England and Wales ... ... | 3·8 | 5·1 | 7·6 | 14·7 | 38·0 | 128·6 |

These figures are further analysed in Tables II., III., and IV.

TABLE II.—DEATH-RATES FROM ACCIDENT PER 1,000 LIVING AT EACH AGE-PERIOD.

| Age-period. | | 15-25. | 25-35. | 35-45. | 45-55. | 55-65. | Over 65. |
|---|---|---|---|---|---|---|---|
| 1849-1853 | All males ... ... | 0·9 | 1·0 | 1·15 | 1·4 | 1·6 | — |
| | Coal-miners ... ... | 5·7 | 5·3 | 6·2 | 6·9 | 5·9 | — |
| 1900-1902 | Occupied and retired males ... ... | 0·5 | 0·6 | 0·8 | 1·0 | 1·4 | 2·1 |
| | Occupied and retired coal-miners ... ... | 1·2 | 1·2 | 1·6 | 2·1 | 2·7 | 3·3 |

TABLE III.—DEATH-RATES FROM LUNG DISEASE PER 1,000 LIVING AT EACH AGE-PERIOD.

| Age-period. | | 15-25. | 25-35. | 35-45. | 45-55. | 55-65. | Over 65. |
|---|---|---|---|---|---|---|---|
| 1849-1853 | All males ... ... | 3·6 | 4·8 | 5·3 | 6·8 | 9·6 | — |
| | Coal-miners ... ... | 3·5 | 3·1 | 3·7 | 7·1 | 16·3 | — |
| 1900-1902 | Occupied and retired males ... ... | 1·4 | 2·9 | 4·6 | 6·6 | 10·0 | 22·2 |
| | Occupied and retired coal-miners ... ... | 1·0 | 1·6 | 2·4 | 4·9 | 12·5 | 36·1 |

TABLE IV.—DEATH-RATES FROM OTHER CAUSES THAN ACCIDENT OR LUNG DISEASE PER 1,000 LIVING AT EACH AGE-PERIOD.

| Age-period. | | 15-25. | 25-35. | 35-45. | 45-55. | 55-65. | Over 65. |
|---|---|---|---|---|---|---|---|
| 1849-1853 | All males ... ... | 3·6 | 4·3 | 6·3 | 10·7 | 20·6 | — |
| | Coal-miners ... ... | 5·3 | 6·1 | 7·3 | 12·3 | 21·8 | — |
| 1900-1902 | Occupied and retired males ... ... | 1·6 | 2·8 | 5·5 | 11·1 | 24·2 | 81·7 |
| | Occupied and retired coal-miners ... ... | 1·6 | 2·3 | 3·6 | 7·7 | 22·8 | 89·2 |

It will be seen from Table I. that whereas about 1851 the death-rates at all ages were considerably higher among colliers than among the general population, the converse was the case in 1901. About 1881 the rates had become about equal. In the fifty years from 1851 the death-rate fell greatly among the general population; but the fall is far more striking among colliers than in other occupations. Table II. shows the enormous fall in the accident death-rate among colliers. Table III. brings out the very significant fact that up to the age of about 50 the

death-rate from lung diseases is much lower among colliers than in the average population, and was so even in 1851; whereas above 50 the converse is the case.

The purpose of this paper is, not to discuss the causes of the improvement, but to concentrate attention on the reason for the continued high death-rate among old colliers. According to the census of 1901, out of a total of 609,000 men employed as colliers, 35,800 (or 5·9 per cent.) were aged 55 to 65, and 10,000 (or 1·6 per cent.) above 65. It is thus only to a small proportion of actual colliers that the higher death-rate applies. Nevertheless, this higher death-rate must, if correct, be an index of much invalidity —of the premature wearing-out of many men. Hence the matter is one of serious concern.

As coal-mining is a strenuous occupation, it is natural that colliers should retire or go into some other occupation when they reach a certain age. From the census returns for 1901 it appears that for 1,000 men living at the age of 45 to 55 there were 650 at the age of 55 to 65, and 473 at over 65. Among colliers, on the other hand, for 1,000 employed at 45 to 55 there were only 479 returned as employed at 55 to 65, and 134 at over 65. If those returned as retired colliers be added, the numbers are still only 506 at 55 to 65, and 212 at over 65. It seems, therefore, that a large proportion of colliers do take to other occupations, or for some other reason were not returned as colliers.

Now the numbers of occupied and retired men in each occupation are taken from the census returns. On the other hand, the deaths, and the present or previous occupation to which each death is credited, are returned by the local registrars. If, therefore, the census and the registrars' returns are not both complete, the death-rates calculated from them will be more or less inaccurate. The last Decennial Supplement gives the death-rate for all males over 65 as 94.6 per 1,000, for all occupied males as 88.4, and for occupied and retired males as 106·2. From the figures given it follows that the calculated death-rate for retired males is 148·0. But the total of occupied and retired males above 65 is only 86 per cent. of all males above 65, and the missing 14 per cent. belong mainly, so far as can be judged, to the retired class. The " retired " and " missing " class together have a death-rate of 104·2, and this is probably about the real death-rate of the retired class. There can be no doubt that the returns of previous

and present occupations of old persons by the registrars were much more complete than the census returns, so that the total of old persons to which the corresponding deaths were credited was too small, and the death-rate consequently too high.

This source of error appears to have told with special heaviness on the death-rates calculated for colliers above the age of 55, since so large a proportion of old colliers retire from their work as colliers, but may still come to be entered in either registrars' or census returns as either "occupied," or simply "unoccupied." In general the "retired" class in each occupation has a much higher calculated death-rate in each occupation than the "occupied" class. Most of the excess is only apparent, as just explained; but part is certainly real, and due to the facts that the "retired" class are older on an average, and that retirement has often been due to some ailment which ultimately proved fatal. In the case of colliers over 65, however, the calculated death-rate (109·6) is much lower among the "retired" than among the "occupied" (139·8). The existence of this strange anomaly leaves little doubt as to the incorrectness of the death-rates for occupied and retired colliers as given in the last Decennial Supplement.

By the courtesy of the Registrar-General and of Dr. Stevenson, Superintendent of Statistics, the writer is enabled to refer to a few of the figures belonging to the next Decennial Supplement, which is delayed owing to the staff of the department being largely engaged in war work. These figures refer to the number and calculated death-rates of occupied and retired colliers over 65 in the years 1910-1912. It appears that in the census of 1911, 29,549 men were registered in the census as occupied and retired colliers, whereas only 15,879 were so registered in the 1901 census. It would be absurd to suppose that the number of old colliers had nearly doubled in ten years, so that the 1901 figures are clearly shown to have been wrong. The calculated death-rate among occupied and retired colliers in 1910-1912 was 105·5, instead of the high figure of 128·6 for 1900-1902. The new figure is slightly lower than the corresponding one for all occupied and retired males in 1900-1902, and removes once for all the painful impression produced by the existing published figures.

Whether, and if so to what extent, the true existing death-

rate of occupied and retired colliers above the age of 55 is higher than in other occupations must remain in doubt for the present. The writer thinks, however, that it has been higher in the past; for, even if the older calculated death-rates are discarded, another method of judging is left. Different occupations leave their marks on men, and these marks are shown in tendencies to die more readily from certain affections. Now, if the proportions due to particular causes among the total deaths registered among occupied and retired colliers above the age of 55 be analysed, there appears to be a marked excess of deaths from bronchitis. This fact, as well as the great difference between different occupations with regard to the mortality from bronchitis in old age, is shown in Table V.

TABLE V.—OCCUPIED AND RETIRED MALES ABOVE 65 IN ENGLAND AND WALES, 1900-1902.

| Occupation. | Deaths from bronchitis as percentage of total deaths. | Calculated death-rate from bronchitis per 1,000. |
|---|---|---|
| All occupied and retired males ... ... | 13·2 | 14·1 |
| Clergymen ... ... ... ... ... | 6·5 | 5·3 |
| Shopkeepers ... ... ... ... ... | 11·8 | 10·6 |
| Farm labourers ... ... ... ... | 12·2 | 11·9 |
| Carmen and carriers ... ... ... ... | 16·8 | 20·0 |
| Dock labourers... ... .. ... ... | 21·5 | 20·9 |
| Coal-miners ... ... ... ... ... | 19·6 | 25·2 |
| Coal-miners, 1910-1912 ... ... .. | 17·6 | 18·4 |

This table indicates that there is a rough general relationship between mortality from bronchitis in old age and work involving considerable physical exertion. Many other occupations bearing out the same general conclusion might have been included.

TABLE VI.—COAL-MINERS ABOVE 65 IN ENGLAND AND WALES.

| Years. | Deaths from bronchitis as percentage of total deaths | | Calculated death-rate from bronchitis per 1,000. | | Total calculated death-rate per 1,000. | |
|---|---|---|---|---|---|---|
| | Occupied. | Occupied and retired. | Occupied. | Occupied and retired. | Occupied. | Occupied and retired. |
| 1890-1892 | 26·0 | — | 38·1 | — | 146·4 | — |
| 1900-1902 | 20·0 | 19·6 | 28·0 | 25·2 | 139·8 | 128·6 |
| 1910-1912 | 18·1 | 17·6 | — | 18·4 | — | 105·5 |

Let us now look at the bronchitis mortality among old colliers, as indicated by the figures of successive Decennial Supplements. Table VI. shows the figures since data on the subject were first published.

The table indicates very clearly that bronchitis has diminished greatly among old colliers since 1890, although it is still in excess.

The excessive bronchitis death-rate among colliers in 1890-1892 was probably due to a considerable extent to the prevalence of dangerous influenza at that time, since the bronchitis death-rate was higher in all classes of the community than in 1900-1902. But the *relative* excess among old colliers is none the less significant.

Table V. points, as already remarked, to a connexion between excessive physical exertion and a tendency to die of bronchitis in old age. Now hard physical exertion is accompanied by hard breathing. The body does not wear out like a machine, since its substance is constantly being renewed; indeed, the maintenance of each organ is improved by due use. But over-use does produce injuries, and constant over-distension of the lungs tends to bring about what is known as "emphysema"—a condition in which the delicate walls of the air-cavities of the lungs are more or less ruptured. With emphysema existing bronchitis becomes more dangerous; and it would seem that the increased tendency to death from bronchitis in occupations involving excessive exertion is due to the emphysema induced by over-stretching of the lungs during that exertion.

But why has bronchitis in old age diminished so greatly among coal-miners? Improvement in ventilation seems the most probable cause. So far as the writer can judge from enquiries, it was common 40 or 50 years ago for coal-miners to be working in air containing so much blackdamp that lamps or candles burned dimly. In such air there is usually 2 or 3 per cent. of carbon dioxide, which has an enormous effect in increasing the breathing during muscular exertion. The breathing is exactly regulated so as to keep an average of about 5·6 per cent. of carbon dioxide in the air filling the air-cavities of the lungs; and with 3 per cent. of this gas in the air a man breathes twice as much air, so as to keep the percentage right in the lungs. A man doing moderate muscular work in pure air

would breathe about five or six times as much air as during rest. In air containing 3 per cent. of carbon dioxide he would be breathing ten or twelve times as much air as during rest, and his breathing would be taxed to the utmost. He would thus be much more liable to contract emphysema.

The better ventilation of coal-mines is largely a consequence of the greater amount of firedamp and greater heat met with as mines have become deeper, and the writer is inclined to think that both the firedamp and the heat have hitherto resulted indirectly in great improvement to the health of miners. Where there is plenty of firedamp there is usually also plenty of fresh and dry air, and no harmful excess of carbon dioxide. The proportion of deaths from bronchitis among old miners was higher in Staffordshire in 1890-1892 and 1900-1902 than in any of the other coalfields; and Staffordshire mines are on the whole exceptionally subject to blackdamp.

The excess in bronchitis among old coal-miners has been attributed to the breathing of dust, and the writer was previously inclined to agree with this theory. But it is very difficult to see why, if dust is the cause, there has been so great a diminution in the bronchitis mortality in recent years. Coal-mines have, on the whole, become drier and more dusty with increasing depth and better ventilation; and, if dust were the cause, one would have expected the bronchitis to increase, whereas it has greatly diminished.

It is certainly the case that an excess in mortality from bronchitis is associated with the breathing of harmful dust. But this excess is accompanied by a far greater excess in mortality from phthisis, and begins comparatively early in life, unlike the bronchitis mortality of colliers.

The experiments carried out by Prof. J. M. Beattie on animals for the Eskmeals Committee showed that both coal-dust and the shale-dust usually associated with it on mine roads are relatively harmless. Further experiments on the same subject have been carried out more recently by Dr. A. Mavrogordato in the writer's laboratory for the Medical Research Committee under the Insurance Act, and attention has been concentrated on the process by which dust is eliminated from the lungs. These experiments show that both coal-dust and shale-dust are readily eliminated by the agency of living cells, which collect

the dust and then wander out with it into the bronchial tubes, whence it is swept upwards by the action of the ciliated epithelium which lines the air-passages. This ready elimination does not occur with other dusts known by human experience to be dangerous and liable, in particular, to predispose the persons concerned to phthisis.

To put the matter into metaphorical language, coal-dust and shale-dust, when introduced into the lungs, summon up the activities of thousands of tiny housemaids, who collect and gradually make away with the dust. If the quantity of dust inhaled is not too great, therefore, the cleaning-up process keeps pace with the introduction of the dust, and no harm results.

It is well known that colliers suffer very little from phthisis. The facts are so striking that the writer has embodied them in Table VII., which is constructed from data in the last Decennial Supplement.

TABLE VII.—DEATH-RATES FROM PHTHISIS PER 1,000 LIVING AT EACH AGE-PERIOD FOR ENGLAND AND WALES, 1900-1902.

| Age-period. | 15-25. | 25-35. | 35-45. | 45-55. | 55-65. |
|---|---|---|---|---|---|
| All occupied and retired males ... ... | 1·1 | 2·1 | 2·9 | 3·2 | 2·6 |
| Occupied and retired coal-miners ... ... | 0·7 | 1·0 | 1·1 | 1·5 | 2·0 |
| ,, ,, ,, farm labourers ... | 0·6 | 1·15 | 1·3 | 1·4 | 2·6 |
| ,, ,, ,, tin-miners ... ... | 0·4 | 7·0 | 11·7 | 16·1 | 16·2 |

This table shows that the phthisis death-rate among colliers is not only much lower than in nearly all other occupations, but is even lower than in the exceptionally healthy occupation of farm labourer, despite the advantages of pure air and relative segregation in the latter occupation. The low death-rate from lung disease among colliers up to the age of 55 is almost entirely due to their relative immunity from phthisis, and Table III. indicates that this immunity existed in 1850 just as now. Above the age of 55 their increased bronchitis death-rate in old age begins to tell heavily, and their general death-rate probably goes up correspondingly. For contrast, the figures for tin-miners, who are exposed to dangerous dust, are added in the table.

Coal-dust certainly does not kill germs; but it has come to be regarded by medical men as a preventive of phthisis. It seems probable, therefore, that the "housemaid" cells which clear

out the dust-particles clear out at the same time other "foreign bodies," such as tubercle bacilli. If this is so, coal-dust in moderation is, on the whole, and despite explosions, an advantage to the safety of colliers. Town-dwellers and smokers may also take comfort to themselves in the thought that, in introducing smoke-particles into their lungs, they are educating their lung epithelium to deal with really harmful "foreign bodies." In any case the evidence does not now bear out the theory that the excessive bronchitis of old colliers is due to dust-inhalation.

The writer does not think that there is any evidence in favour of the idea that the excessive bronchitis in old colliers is due to exposure to changes of temperature. Miners do not appear to take harm in this way, so far as the writer has been able to ascertain; and in other occupations associated with exposure to extremes of weather, there is no excess of bronchitis among either young or old.

The practical conclusions to be drawn from this paper are: (1) that good ventilation is of considerable importance to the health and continued working efficiency of miners, as well as to their safety from accidents; and (2) that there is no real statistical evidence of harm resulting from the inhalation of coal-dust or shale-dust in the quantities ordinarily breathed by miners, and a strong presumption that the dust they breathe protects them against serious dangers.

It is satisfactory to find that the excessive death-rate among old colliers is to a large extent only apparent, and that the real excess of bronchitis from which they have suffered has greatly diminished.

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Prof. Henry Louis (Armstrong College, Newcastle-upon-Tyne) suggested that it would add to the interest of the paper if tables were added giving the rates of wages paid to colliers during the periods dealt with. He thought that it would be found that wages played an exceedingly important part in the subject under discussion: first, because an increase in the rates of wages enabled a man to live much better from childhood upwards, and, secondly, because his better nourished body put him in a position to ward off disease. The wages earned at present by the collier allowed him to retire at a comparatively early age, and thus, being a man

who had done a shorter spell of work in the pits and who was living a comfortable life in his retirement, he would be more immune from diseases than if he had had to continue work for a much longer period. It was very satisfactory to the coal-mining industry to learn from the paper that the efforts that had been made to improve the ventilation, etc., had been of direct benefit to the health of the men employed in the mines.

Mr. D. M. Mowat (Coatbridge) said that Dr. Haldane had pointed out the great handicap under which a man working in bad air suffered, and the danger that he ran when working hard compared with a man who was quietly sitting still. It never paid to work a man in bad air, and nobody did it if he could avoid it, because, apart from the danger to the man himself, there was the question of expense. A man working in bad air could not do the amount of work that he otherwise would, and he would want to be paid a higher rate for so doing.

Mr. Arnold Lupton (London) said that he had long been of opinion that, in considering the safety of mines, it was necessary to take into account the sanitary conditions as well as the accident factors. Too much thought had been given in the past to the question of how to avoid accidents, without taking into consideration whether the methods adopted would introduce injuries to health that might cause far more deaths, disease, and misery than the occasional accidents which were so much deplored when they did arise. He would like to call attention to the danger from flint and granite dust, which was so harmful in the case of the Cornish tin-miners. What was the effect of the dust thrown up from the granite roads and other hard roads on people who lived beside them, or travelled on them, as compared with those who lived, say, near asphalted or wood-paved roads? Had asphalte or wood any special dangers of their own? It was mentioned in the paper that the grains of coal-dust or shale breathed by the colliers might help to carry out of the system the tubercle bacilli. Would the author pursue his investigations a little further, because he (Mr. Lupton) was of opinion that this belief in the tubercle bacillus as a cause of consumption was one which in a very short time the progress of science would prove to be erroneous. When the bacillus was found, it was a consequence, and not a cause.

Mr. T. H. Bailey (Birmingham) asked whether the effect of ventilation in workmen's houses in improving the health of colliers was not as important as the factors mentioned by Dr. Haldane in his paper. He had made enquiries in one of the working-class parishes of Birmingham, and found that during the past 20 years the health of the residents had vastly improved, as they were getting more into the habit of keeping their windows open both day and night. He was of opinion, therefore, that the ventilation of houses was quite as important as the ventilation of the places in which they worked.

Lieut.-Colonel W. C. Blackett (Sacriston) said that he was somewhat puzzled by the statistics put forward by Dr. Haldane. He did not know why the conclusion was arrived at that the highest death-rate of the older men was "an index of much invalidity—of the premature wearing-out of many men." If lives of various ages were saved during the earlier periods, and the men thus prevented from dying prematurely, a time would come at a later stage when they must die. This, however, did not prove that there was any alarming death-rate among the older men, as it was a natural consequence of the men having been prevented from dying earlier. If it were possible to keep such men alive until they were, say, 100 years old, and they all died at that age, it would be very easy to comment upon the extraordinary death-rate of men of 100 years as against a previous period when no one had ever died at that age. He was, therefore, by no means convinced that the statistics in the paper proved exactly what Dr. Haldane contended. The author had also stated that the prevalence of bronchitis was, as a rule, due to men working very hard, and later on he had answered the question why bronchitis in old age diminished so greatly among coal-miners by stating that it was owing to the improvements in the ventilation. It was rather illogical to state first that this bronchitis was mostly due to men working strenuously, and then to account for it by a totally different reason. It might be equally due, as Prof. Louis had hinted, to the fact that the men who formerly worked very hard did not do quite so much work now. This was quite a reasonable supposition, because men nowadays did not work quite so hard as they did in the olden times, when they worked much longer hours.

He would like to ask whether ordinary breathing, even if rapid, by expansion of the chest under atmospheric pressure, could damage the lung cell and cause emphysema as much as could forcible distension of the cell by contraction of the chest. He would like to hear more about other occupations in this connexion--say, the glass-blower, who did forcibly distend his lungs. Would he not much more readily suffer than the men who simply extended their lungs by allowing the air to enter at ordinary atmospheric pressure?

Dr. J. S. HALDANE (Oxford), in reply, said that the glass-blowers' occupation did give rise to emphysema, and the same remark applied to people who played wind instruments, although there were exceptions in every case.

With regard to the question of hard work, if a man did not work so hard now, it might account for there being less emphysema; but his impression, after seeing colliers at work, was that it was not the number of hours that they worked, but the amount of labour that they put into their work. There appeared to be a very big strain on their lungs when they were not breathing perfectly pure air, but it was quite possible that colliers had not worked so hard during the last 20 years as in previous years. With regard to the invalidity question, he was afraid that he had not made himself quite clear. All he meant to infer was that there might be extra invalidity because the colliers were more liable to bronchitis. If they got emphysema, it would be at a time when they ought to be working in good health, instead of which they were wheezing and unable to do any considerable work or make a livelihood. He did not think that people were on the whole less healthy for not having been killed off in their youth.

Lieut.-Colonel BLACKETT said that the figures set forth in the paper showed, however, that such was the case. If Dr. Haldane would examine Table III. ("Death-rates from Lung Disease"), he would see that at the first, second, third, and fourth age-periods there were fewer deaths from this cause than was the case amongst other classes. It was not until the fifth and sixth stages were reached that the deaths were more, and that, he maintained, was because "creaking hinges" had at last given way. That was, he contended, the logical conclusion to be drawn from the table.

Dr. HALDANE said that, if Colonel Blackett would examine the figures again, he would find that what really had happened was that the men died less from phthisis at any age up to extreme old age, but that apparently at the age of 50 they began to die of bronchitis in a way that no other people did. It was not because there were more of them: for it was the rate per thousand living at that particular age that he had dealt with.

With regard to Mr. Bailey's remarks as to the benefit arising from open windows, he quite agreed with him on that point; but the liability to bronchitis was a special factor which he did not think had anything to do directly with open windows. They probably helped considerably in the diminution in the death-rate in the general population, and the death-rate, of course, had diminished, but he was not sure that this factor applied much to those working underground.

Mr. Lupton had raised a very interesting question about the breathing of dust from roads, and asked whether it did harm. It was quite possible, however, that the amount of horse manure lying on the road might act as a preventive and save us from miners' phthisis. He did not actually mean to suggest that this was the case, but its presence was one of those little things that made all the difference. The question whether one dust was not an antidote for another was now being worked out —whether, for instance, a dust which by itself would be dangerous would be rendered innocuous in the presence of coal-dust. Thus the introduction of coal-dust into the Transvaal mines might result in clearing out from the cells of the lungs the whole of the dangerous silica dust as well as other harmful matter. These were all very interesting questions, but at present there were no proper data available respecting them. There were, however, data with regard to shale-dust, and there was no doubt that it contained quartz. Dr. A. Mavrogordato was now working at this question. The quartz seemed to be all cleared out of the lungs when shale-dust was given to animals, whereas pure quartz was not. He would have been inclined to agree with Prof. Louis's suggestion respecting the effect of high wages, except for the fact that, taking the case of farm labourers, whose wages were extremely low as compared with other classes, it was found that they had the least general mortality. They did not stand quite so well in phthisis, but in other complaints their status was

better, although their wages were extremely low when compared with those of colliers. It was, of course, essential that a man and his family should have enough food to enable him to lead a healthy life, but he was not sure that the wages question had very much to do with the death-rate of colliers. That, however, was a matter of opinion.

Mr. JOHN GERRARD (Worsley) called attention to the fact that the statistics in the paper took them down to the year 1902. The Eight Hours' Act came into force in 1909, and was followed by the Minimum Wage Act, the abnormal places rates, and war bonuses, all of which meant considerable advances in wages. The effect of these enactments would be shown in subsequent tables.

Dr. EDGAR L. COLLIS (Medical Inspector of Factories, Home Office) wrote that the exact causation of the high respiratory mortality at late ages could not be ascertained until the various groups classed as miners were subdivided; thus the working conditions of (1) coal-getters, (2) road-makers underground, and (3) other men engaged about a coal-mine, varied considerably. Bronchitis, however, which was chiefly considered, was a condition causing much *pre-mortem* invalidity: a study of such invalidity among the various groups indicated would probably afford useful and sufficient data. The varying mortality from this disease among miners in different coalfields was of great interest, and worthy of close study.

Mr. CHARLES CARLOW (Leven, Fife) wrote that one of the miners at the collieries belonging to the Fife Coal Company, Limited, had recently retired from active underground work at the age of 82. This man had commenced work at the age of 10 at Kelty Colliery, and had worked in the same mine for 71 years, with the exception of three weeks. He (Mr. Carlow) had taken over the management of that colliery 43 years ago, and in 1914 had at his table thirty-five workmen (from 65 to 80 years of age) who had never left the colliery during that period. They had all been hard-working loyal fellows, and were in very good health for their years. Some of them had retired, but most of them were still working. The output of Kelty Colliery in 1873, when these thirty-five old men were at work there, was only 300 tons

per day, so that they represented a considerable proportion of the total men employed.

Mr. W. B. Wilson, Junr. (Chopwell) wrote that his experience was that bronchial and asthmatical colliers were particularly sensitive to the fumes produced by explosives, even under conditions which caused absolutely no inconvenience to colliers in normal health. This inconvenience might be only temporary, but he was inclined to think that it was serious, and that possibly the previous use of explosives in moderately ventilated mines was in some degree the original cause of bronchitis among the aged colliers of to-day. If this opinion were correct, the present higher standard of ventilation might produce a greater improvement in the mortality from bronchitis among aged colliers than was anticipated by Dr. Haldane. Tables comparing the mortality from bronchitis among aged coal-miners and aged metal-miners would have been instructive. Generally speaking, metal-miners use more explosives than coal-miners. The dust produced was injurious, and the men had frequently to perform the very laborious work of climbing long vertical ladders. The use of vertical ladders was now not as frequent as was the case a few years ago, and Dr. Haldane would probably be in a position to state how the percentage of blackdamp in metal-mines compared with the percentage met with in coal-mines.

Dr. Haldane wrote that, while he agreed with Dr. Collis, he feared that it would not be possible in practice to classify coal-miners according to the nature of their work, as they went from one class of employment to others.

What Mr. Wilson had stated about the effects of fumes from explosives would certainly help to explain the fall in the bronchitis death-rate among old colliers. In his (Dr. Haldane's) experience there was less blackdamp in the air of metal-mines (where the dust was dangerous) than in most coal-mines.

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The following papers were read in abstract by Mr. T. F. Winmill:—

# THE ESTIMATION OF MOISTURE IN COAL.

BY T. F. WINMILL, B.A., B.Sc., DONCASTER COAL-OWNERS' LABORATORY.

The determination of the percentage of moisture in coal is a question which has received much attention from various investigators, all of whom are agreed that the usual method of heating coal in an air-oven to 110° Cent., and assuming the loss in weight after such heating to be due to the loss of moisture alone, is one liable to serious error. It is unnecessary to refer in detail to all the previous papers on this subject, but reference may be made to the special report of the Eighth International Congress of Applied Chemistry, and to a paper by Messrs. Huntley and Coste,* in which this report is discussed. In these two papers complete references to earlier work may be found. The general conclusions reached are that, in order to determine accurately the moisture in coal, the drying should be done either *in vacuo* or in a current of a dry gas which is without action on the coal. In a very large number of cases a high degree of accuracy is not required in the estimation of the moisture percentage in a sample of coal, for local variation and the difficulties of sampling may introduce uncertainties as great as the experimental errors. In other cases, however, it is necessary to know with some accuracy the percentage of the various constituents of the coal, and this is especially the case when a selected sample has been the subject of some particular experiment, or is required for an ultimate analysis. Since most of the analyses made in the Doncaster Coal-owners' Laboratory are on selected samples, some experiments have been conducted with the object of devising a simple, rapid, and accurate method for the determination *in vacuo* of the moisture content of coals. The results obtained have been compared with those arrived at by the more general method of heating the coal in an air-bath to 105°-110° Cent. It is obvious that the loss of weight found by this latter method is really the balance of five factors, namely:—

* "The Determination of Moisture," by G. N. Huntley and J. H. Coste, *Journal of the Society of Chemical Industry*, 1913, vol. xxxi., page 62.

(1) Loss in weight due to the loss of moisture.

(2) Loss in weight due to the expulsion of the gas from the coal.

(3) Gain in weight due to the absorption of oxygen by the coal.

(4) Loss in weight due to the formation of water and carbon dioxide by the interaction of the carbon and hydrogen of the coal and the oxygen of the air.

(5) Gain in weight due to the reabsorption of moisture by the coal from the air during cooling and weighing.

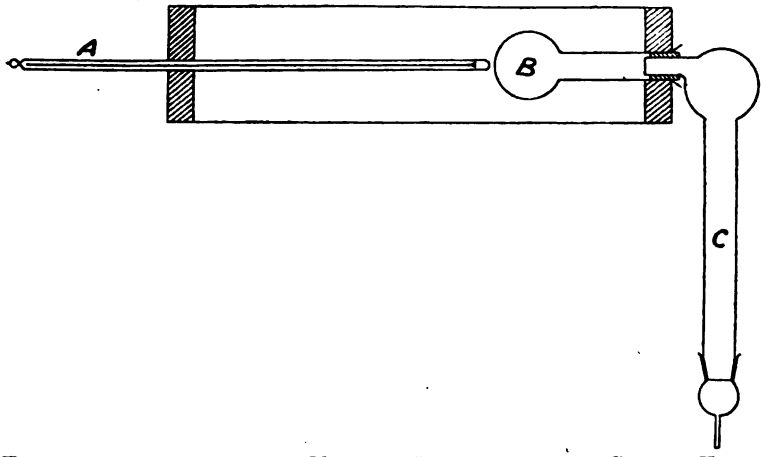



FIG. 1.—APPARATUS USED FOR MOISTURE DETERMINATION IN COAL *IN VACUO*.

Of these five quantities, as a rule the first is far the largest; the second and fourth tend to make the apparent quantity of moisture larger; whilst the third and fifth would act in the opposite direction, and so tend to neutralize the possible error.

From experiments described in previous papers from this laboratory* it appears that the gain in weight due to the absorption of oxygen by coal at 100° Cent. may be large, and, as is shown later, amounts to 1·7 per cent. in an hour in the case of some lignites, although in other less oxidizable coals the gain is very much smaller. The loss of gas from a ground sample of coal causes a variable error, depending on the length of time during which the dust has been exposed to the air before being weighed. Except in the case of a few of the most gassy Welsh coals, the possible error from this source seldom exceeds 0·05 per cent.

* *Trans. Inst. M. E.*, 1913, vol. xlvi., page 563; 1914, vol. xlviii., pages 503, 508, 514, 521, and 535; and 1915, vol. xlix., page 35.

The quantity of hydrogen from the coal which may be oxidized to water by the air has not been directly determined in detail in the present paper, but is the subject of separate experiments by Mr. J. T. Graham, of this laboratory.

The fifth factor (the absorption of moisture by the dried coal) is often of great importance, and is discussed later.

All these uncertainties may be avoided by heating the coal *in vacuo*, and by collecting and weighing the actual moisture given off. A convenient apparatus is indicated in Fig. 1.

An iron tube 4½ centimetres in diameter and 20 centimetres long is covered with a layer of asbestos-paper, and on this is wound a length of resistance wire. This coil is insulated on the outside with asbestos-paper, and connected through an adjustable resistance to the lighting mains. By a suitable variation of this outside resistance, any desired temperature can be obtained inside the iron tube, and without further attention will remain constant all day to within a few degrees. The temperature is read on the thermometer *A*, which is carried in the position shown by a cork fitted into the end of the iron tube. A small flask *B*, having a bulb 2½ centimetres in diameter, a neck 4½ centimetres long and 1 centimetre bore, is held by a divided cork (so as to facilitate its easy removal) in the other end of the iron tube. Into the neck of the small flask a glass tube *C*, containing anhydrous calcium chloride, is fitted by means of a rubber stopper. The other end of *C* is closed by a well-ground hollow glass stopper, which is connected by rubber pressure tubing to a second calcium-chloride tube, which in turn is connected through a two-way tap to a sulphuric-acid wash-bottle, and thence to a Bunsen vacuum-pump. The calcium-chloride tube *C* is 12 centimetres long by 1¼ centimetres bore. The bent portion at the top is 1½ centimetres long by ¾ centimetre in diameter. Just below this bend the main portion of the tube is enlarged into a bulb, as shown, so that when the calcium chloride becomes moist by the absorption of water, it may not clog the tube.

When a determination is being made, the electric oven is first brought to a temperature of 105°-110° Cent. About 2 grammes of the powdered coal sample are then weighed into the flask *B*, and the tube *C* is weighed accurately. The apparatus is then joined up; and the pump turned on until a pressure of 20 millimetres is obtained. The flask *B* is then put into the

electric oven, as shown in the sketch, and left for half an hour with the pump still working. If, however, the coal contains more than 10 per cent. of moisture, it is well to extend the heating to three-quarters of an hour in some cases. At the end of this time, the flask is taken out of the oven and allowed to cool for five minutes, after which the two-way tap is opened to the atmosphere,* and air allowed to enter. The apparatus is then disconnected, the flask *B* securely stoppered, and the tube *C* again weighed. The increase in weight of *C* is the quantity of water contained in the sample of coal weighed into *B*. Since oxygen has been absent, and since calcium chloride will not absorb the gases given off by the coal, the estimation made in this way is free from the errors that may occur when the coal is heated in air.

The dried coal left in *B* after the determination, if the flask has been well stoppered immediately after being disconnected from the apparatus, may be used for subsequent analyses of the coal for ash, carbon, hydrogen, etc.

In Table I. some determinations of the percentage of moisture by the method described above are set forth in column A. In column B parallel results obtained from the same samples at the same time, obtained by heating the coal to 105°-110° Cent. in air, are recorded.

TABLE I.—DETERMINATIONS OF MOISTURE.

| Sample. | A. Per cent. of moisture determined *in vacuo*. (1) | (2) | B. Per cent. of moisture by heating in air to 105°-110° Cent. (1) | (2) |
|---|---|---|---|---|
| 1 ... ... ... | 3·61 | 3·59 | 2·87 | 2·92 |
| 2 ... ... ... | 8·63 | 8·60 | 7·67 | 7·54 |
| 3 ... ... ... | 28·50 | 28·60 | 27·22 | 27·11 |
| 4† ... ... ... | 1·27 | 1·28 | 1·12 | — |
| 5 ... ... ... | 8·12 | 8·16 | 7·70 | — |
| 6 ... ... ... | 11·42 | 11·48 | 10·91 | — |
| 7 ... ... ... | 29·65 | 29·70 | 27·12 | — |

These two sets of results for the moisture percentage in the same samples show a very wide divergence, indicating some

* If the two-way tap be opened too quickly, dust from the calcium-chloride tube may be blown into the small flask *B*, or more commonly coal-dust from *B* is blown back into *C*. In order to avoid this, it is a good plan to connect about 10 centimetres of thermometer tubing (part of the stem of a broken thermometer answers) by rubber pressure tubing to that limb of the two-way tap which is open to the air. The tap may then be turned full open without any fear of the air entering too violently.

† For samples Nos. 4 to 7 and for their analysis under column B the writer is indebted to Mr. W. McD. Mackey, Leeds.

serious error in one or both of the methods employed. Reasons have already been given for supposing that it is the results tabulated in column B (which were obtained by the method in general use) that are very unreliable, and further experiments were carried out to find whether the sources of error already enumerated would account for the differences between the two series. As will be seen from what follows, the two chief sources of error—the oxidation of the coal in air, and the reabsorption of moisture from the air—introduce errors sufficient to account for these differences.

First, however, the possibility that all the water is not expelled from the coal in the air at 105° Cent. after an hour had to be considered. The following tests show, nevertheless, that drying is complete in a much shorter time:—

A sample was heated at 105° Cent. for one hour, and then, without being removed from the oven, was tipped into a small flask, which had been placed in the oven ready for its reception. This flask was then connected up to the calcium-chloride tube, and a determination of the residual moisture made in the vacuum apparatus. As was to be expected, the test showed that all the moisture had already been expelled from the coal in the air-oven.

This result was confirmed by heating samples of coal in the air and weighing them at intervals in order to see how quickly the moisture evaporated from them. The results are set forth in Table II., the coals used being part of the samples carrying the same numbers in Table I.:—

TABLE II.—PERCENTAGE LOSS IN WEIGHT BY HEATING COAL AT 105° CENT. IN AIR.

| Loss after minutes. | Sample. (1) | (2) | (3) |
|---|---|---|---|
| 5 | 2·94 | 8·17 | 25·68 |
| 10 | 3·33 | 8·19 | 26·66 |
| 20 | 3·20 | 8·20 | 27·11 |
| 40 | 2·96 | 7·90 | 27·30 |
| 60 | 2·92 | 7·69 | 27·09 |
| Percentages found *in vacuo* | 3·60 | 8·61 | 28·55 |

These figures indicate that the moisture is driven off from the coal very rapidly indeed, and that, except in the case of lignites, all the moisture has gone in about 10 minutes. If the heating is continued longer, instead of a further loss in weight the coal actually gains weight. This gain is certainly due to oxidation of the coal, as will be clear from a consideration of the measured

rate of oxidation of sample 2. At 100° Cent. this coal gave the following figures:—

Oxygen absorbed per hour after 1½ hours = 208 cubic centimetres per 100 grammes of coal.

Oxygen absorbed per hour after 2 hours = 160 cubic centimetres per 100 grammes of coal.*

Now the *minimum* quantity of oxygen absorbed within the first hour can be calculated by assuming that the rate of oxidation falls during the first hour and a half at the same rate as that at which it falls between one and a half and two hours. Experiment shows that it actually falls faster during the first hour, but, as the *minimum* is being calculated, this increased fall may be neglected. The initial rate of absorption will then be—

$$208 + (3 \times 48) = 352 \text{ cubic centimetres}$$

at the beginning of the oxidation, and—

$208 + 48 = 256$ cubic centimetres at the end of the first hour.

The total quantity of oxygen absorbed within the first hour is then—

$$\frac{256 + 352}{2} = 304 \text{ cubic centimetres per 100 grammes of coal.}$$

This oxygen may be used up in one or all of three ways, namely:—

(1) By combining, and remaining in combination, with the coal.

(2) By oxidizing some of the carbon to carbon dioxide.

(3) By oxidizing some of the hydrogen to water.

Now it has been shown† that in the initial stages of the oxidation only $\frac{1}{75}$th of the total oxygen absorption goes to form carbon dioxide, and from an experiment described below it appears that very little of the oxygen oxidises the hydrogen of the coal to water. Hence—

Volume of oxygen absorbed by 100 grammes of coal = 304 cubic centimetres, of which the weight = 0·43 gramme;

Volume of carbon dioxide produced = 12 cubic centimetres, of which the weight = 0·02 grammes;

Leaving a total increase in the weight of the coal = 0·41 gramme, or 0·41 per cent., a figure which agrees well with the actual 0·50 per cent. increase observed in Table II.

* *Trans. Inst. M. E.*, 1914, vol. xlviii., page 515. † *Ibid.*, page 518.

The actual rate of oxygen absorption has not been measured for sample 1 at 100° Cent., but it has been measured at 30° and 60° Cent.; at both these temperatures the rate is three-quarters of that observed for sample 2. If this ratio still holds good at 100° Cent., the observed percentage increase in weight should be—

$$0{\cdot}41 \times \tfrac{3}{4} = 0{\cdot}31 \text{ per cent.}$$

This figure again agrees well with the increase noted in Table II. There can be no doubt, therefore, that these increases in weight, after the coal has been heated for 10 minutes, are solely due to the oxygen absorbed by the coal.

Sample 3 does not show the same distinct gain in weight as samples 1 and 2, but this difference is due to the fact that the gain by oxidation is being masked by the continued evaporation of moisture. Table II. shows that the bulk of the water is driven off in the first five minutes, but that after that a very gradual loss in weight continues for another 35 minutes. This change in weight is simply the balance between the loss due to the evaporation of moisture and the gain due to oxidation, and gives no information as to the absolute magnitude of either change. After 40 minutes the oxidation becomes the larger change, and the coal begins to increase in weight; before this time evaporation has been the larger, and the coal has steadily lost weight. Some idea, however, can be obtained of the extent of the oxidation from the rate of absorption of oxygen of the sample. Measurements at 30° and 60° Cent. show that in each case this lignite absorbs oxygen about four times as fast as sample 2. At 100° Cent. this would give an increase of $0{\cdot}43 \times 4 = 1{\cdot}72$ per cent. in weight. Probably, however, about a third of the volume of the oxygen absorbed reappears as carbon dioxide at this temperature, which would cause a decrease of 0·80 per cent., leaving a total increase of 0·92 per cent. Although the fact of this increase is masked by the continued evaporation of water, it still exists, and will cause an error of this amount in the percentages of moisture determined in the presence of air.

*Reabsorption of Moisture by Dried Coal.*—In the experiments, of which the results are given in Table I. (column B), and in Table II., it was found that concordant results were only obtained when the two fractions of the same sample were treated in identical ways after they had been heated. It was found that

the dried coal, on exposure to the air, increased in weight with great rapidity. In order to find how far this affected the results of moisture determinations, samples of coal were dried at 105° Cent. for one hour, and then cooled in a desiccator. When cool they were weighed as rapidly as possible, and then, without the sample being removed from the balance-pan, a new weighing was made five minutes later, and again five minutes afterwards. The results of a series of such weighings are recorded in Table III.:—

TABLE III.—INCREASE IN WEIGHT OF DRIED COAL ON EXPOSURE TO AIR.

| Sample No. | 1. | 2. | 3. |
|---|---|---|---|
| Weight at first weighing ... ... | 1·0000 | 1·0000 | 1·0000 |
| ,, 5 minutes after first weighing | 1·0039 | 1·0072 | 1·0069 |
| ,, 10 ,, ,, ,, | 1·0069 | 1·0132 | 1·0131 |
| ,, 15 ,, ,, ,, | 1·0089 | 1·0168 | 1·0187 |
| ,, 20 ,, ,, ,, | 1·0104 | 1·0207 | 1·0236 |
| ,, 30 ,, ,, ,, | 1·0117 | 1·0257 | 1·0318 |
| ,, 40 ,, ,, ,, | 1·0132 | 1·0293 | 1·0384 |
| ,, 60 ,, ,, ,, | 1·0155 | 1·0349 | 1·0500 |

These numbers are shown graphically in Fig. 2.

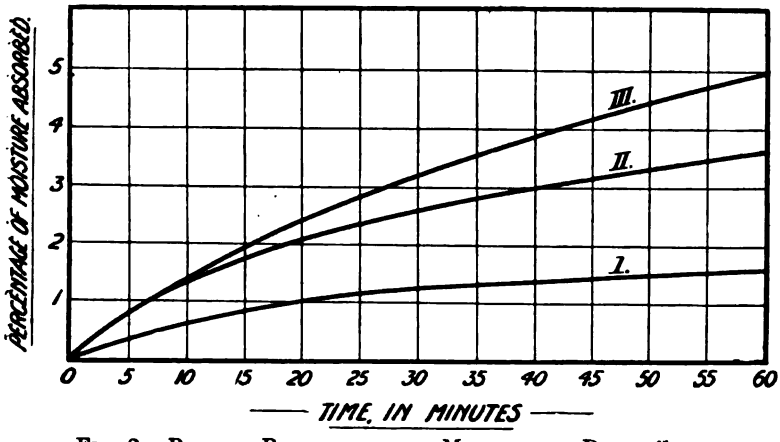



FIG. 2.—RATE OF REABSORPTION OF MOISTURE BY DRIED COAL.

That these increases in weight were due to the absorption of moisture from the air was shown by a redetermination of the moisture in the exposed samples by the vacuum method, when results agreeing well with the observed increases were obtained. They were, however, in all cases higher than the simple increase in weight would have allowed, obviously owing to the fact that, although the first weighings were made as rapidly as possible, they yet occupied a minute or two, during which the coal was

absorbing moisture. Since the increase in weight can only be determined from the first completed weighing, it is obvious that the moisture contained in the sample after a series of weighings will be rather more than the apparent increase in weight.

Any analysis for moisture, therefore, which depends, without special precautions, on a weighing of the coal after drying, cannot fail to be subject to a considerable error. If, in addition, the drying be carried out in air at a temperature of as high as 100° Cent., the effect of oxidation may increase this error to a serious degree. If, however, the estimation be carried out by a direct method, in which the actual water driven off from the coal is collected and weighed, it appears that very little of the hydrogen of the coal is oxidized to water, and a fairly accurate estimation of moisture may be made even in the presence of air. Thus a sample of an oxidizable coal was heated to 110° Cent., in the one case in air and in the other *in vacuo*, the moisture evolved in each case being collected in calcium chloride and weighed. The results, which agreed well, were as under:—

| | | | | |
|---|---|---|---|---|
| Moisture by drying *in vacuo*. | ... | ... | ... | 11·45 per cent. |
| ,, ,, dry air | ... | ... | .. | 11·50 ,, |

When, however, the drying of the coal is a preliminary to some further analysis or experiment, it is obvious that air must be rigidly excluded: for, as has been shown, an oxidizable coal may react with as much as 1·7 per cent. of oxygen, and so modify considerably the proportion of the constituents of the coal.

The conclusions reached in this paper may be summarized briefly as follows:—

(1) The method of estimating moisture in coal by determining the loss in weight of a sample heated to 105°-110° Cent. in an air-bath for an hour is untrustworthy, the results so obtained being too low.

(2) Dried coal has a very considerable power of absorbing moisture, and a sample, after being dried, must be protected instantly if it is to remain free from moisture.

(3) A fairly accurate estimation may be made by heating the coal in a current of dry air at 105° to 110° Cent., and collecting the moisture evolved.

(4) In cases in which it is proposed to use the dried coal for any further experiments, the drying must be done in the absence of oxygen, and this can be done simply and quickly by the vacuum method now described.

# THE ABSORPTION OF OXYGEN BY COAL.

By T. F. WINMILL, B.A., B.Sc., Doncaster Coal-owners' Laboratory.

## Part VIII.—The Effect on the Absorption of the Size of the Coal-particles and the Percentage of Oxygen in the Air.

In a previous paper* it has been shown that the rate of absorption of oxygen by coal is neither directly proportional to the surface area of the coal exposed nor to the percentage of oxygen in the air. Further experiments are now described supporting this conclusion.

*Effect of the Size of the Coal-particles.*—In the earlier experiments (*loc. cit.*) it was found that, if the rate of absorption of oxygen by coal-dust passing a 200-mesh sieve were put at 100, for dust of other sizes the relative rates were as follows:—

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coal passing a 200-mesh sieve ... ... ... ... | | | | | | | | | | | | absorption = 100 | |
| ,, | ,, | 30-mesh but left on a 60-mesh sieve | | | | | | | | | | ,, | = 80 |
| ,, | ,, | 10 | ,, | ,, | 30 | ,, | ,, | | | | | ,, | = 72 |

showing that the absorption is not simply proportional to the outer surface of the coal-dust.

Table I.—Rates of Absorption of Oxygen in Cubic Centimetres per 100 Grammes for Coal just passing through a 2-mesh Sieve.

| Hours. | Barnsley Hards at 30° Cent. | Barnsley Softs at 30° Cent. | Barnsley Hards at 50° Cent. |
|---|---|---|---|
| 1 | 3·4 | 2·2 | 8·05 |
| 2 | 3·2 | 2·1 | 7·75 |
| 4 | 2·8 | 1·9 | 7·2 |
| 6 | 2·5 | 1·75 | 6·7 |
| 8 | 2·25 | 1·6 | 6·2 |
| 12 | 1·85 | 1·4 | 5·3 |
| 18 | 1·5 | 1·2 | 4·25 |
| 24 | 1·3 | 1·1 | 3·4 |
| 30 | 1·15 | 1·05 | 2·85 |
| 36 | 1·1 | 1·0 | 2·5 |
| 48 | 0·95 | 0·95 | 2·15 |
| 72 | 0·8 | 0·8 | 1·65 |
| 96 | 0·7 | 0·7 | 1·35 |

* *Trans. Inst. M. E.*, 1913, vol. xlvi., page 576.

These experiments have been extended to much coarser coal samples. The coal was broken just to pass a 2-mesh sieve, and any fine coal made in the breaking was removed over a 10-mesh sieve. The experimental method was essentially the same as that described in the previous papers, but much larger coal samples (as a rule, about 12 pounds in weight) were used. The rates of absorption of oxygen found are recorded in Table I.

For the purpose of comparison, it may be assumed that when the coal-dust is fine enough to pass a 200-mesh sieve, it shows practically its maximum rate of oxygen absorption. The figures set forth in Table I. can then be expressed as percentages of the maximum rate, and in this way a more direct comparison of the effect of the size of the coal-particles on the rate of oxygen absorption can be obtained.

TABLE II.—RATE OF ABSORPTION FOR DIFFERENT FINENESSES OF COAL EXPRESSED AS PERCENTAGES OF RATE FOR FINEST DUST.

| Hours. | Barnsley Hard Coal | | | | Barnsley Softs at 30° Cent. |
|---|---|---|---|---|---|
| | At 30° Cent. | | | At 50° Cent. | |
| | Passing a 30- but left on a 60-mesh sieve | Passing a 10- but left on a 30-mesh sieve. | Passing a 2- but left on a 10-mesh sieve. | Passing a 2- but left on a 10-mesh sieve. | Passing a 2- but left on a 10-mesh sieve. |
| 2 | 77 | 67 | 17 | 15 | 10 |
| 4 | 80 | 70 | 19 | 22 | 11 |
| 6 | 77 | 72 | 21 | 31 | 12 |
| 8 | 80 | 69 | 23 | 34 | 13 |
| 12 | 82 | 70 | 26 | 37 | 15 |
| 18 | 83 | 72 | 27 | 37 | 17 |
| 24 | 80 | 73 | 27 | 38 | 20 |
| 36 | 80 | 74 | 30 | 38 | 23 |
| 48 | 82 | 74 | 30 | 40 | 24 |
| 72 | 79 | 72 | 31 | 41 | 28 |
| 96 | 79 | 74 | 37 | 40 | 30 |

It appears from Table I. that in a given time coarse coal will absorb less oxygen than fine coal-dust; but from Table II. it is clear that, as time goes on, the difference in the rates of absorption becomes somewhat less, indicating that after a very long time the total quantity of oxygen absorbed by coal is practically independent of the state of division. It follows, therefore, that the same total quantity of heat will be produced ultimately by the atmospheric oxidation of either lump-coal or coal-dust. The rate of production of heat is, however, so very much slower from

the former than from the latter that the heat produced has every chance to become dissipated and so avoid any increase in the temperature of the coal.

Any subsequent regrinding of the coarse coal much increases the rate at which oxygen is absorbed. Thus coal which passed a 2-mesh sieve, and had been exposed to the air for 96 hours at 30° Cent., had then an absorption of only 0·7 cubic centimetre per 100 gramme-hour. When this sample was reground to pass a 200-mesh sieve, the rate increased to 11·5 cubic centimetres 1 hour after the regrinding, and from this point fell off along the normal absorption-time curve for fine dust at 30° Cent. This result is what might be expected, since in 96 hours the coarse coal had absorbed 115 cubic centimetres of oxygen, a quantity which would have been absorbed by the fine dust in 6 hours, after which the absorption would have been 11·8 cubic centimetres.

The curve connecting absorption and time is somewhat flatter in the case of the coarser coals, but the characteristic shape remains very much the same as for the finest dusts. It is, however, clear that the rate of oxidation is not simply proportional to the outer surface of the coal-particles. The comparison can be made in one or two ways—either from the rates of oxidation after each sample has absorbed a definite quantity of oxygen (that is, the samples are equally "fresh"), which is perhaps the more correct theoretically, or by comparing the progressive rates of oxidation stated in Table II.

TABLE III.—COMPARISON OF RATE OF OXIDATION OF COAL AND SIZE OF COAL-PARTICLES.

| Particulars. | Passing a 200-mesh sieve. | Passing a 30-but left on a 60-mesh sieve. | Passing a 10-but left on a 30-mesh sieve. | Passing a 2-but left on a 10-mesh sieve. |
|---|---|---|---|---|
| Approximate ratio of surfaces ... ... | 100 | 20 | 7·5 | 1·7 |
| Ratio of absorption on equally "fresh" samples ... ... | 100 | 60 | 40 | 6 |
| Average ratio of absorption during the first 96 hours ... | 100 | 80 | 72 | 27 |

Obviously, then, the oxidation is not a simple surface action: the oxygen in some manner penetrates the coal-particles.

The state of division of the coal has clearly a most important bearing on the possibility of spontaneous heating in the light of

the experiments described. Other factors being equal, it appears that coal-dust is far more likely to originate combustion than lump-coal, and it is owing to the favourable conditions set up by the grinding of the coal and the regulation of the air-supply that fires so often start in breaks in the coal.

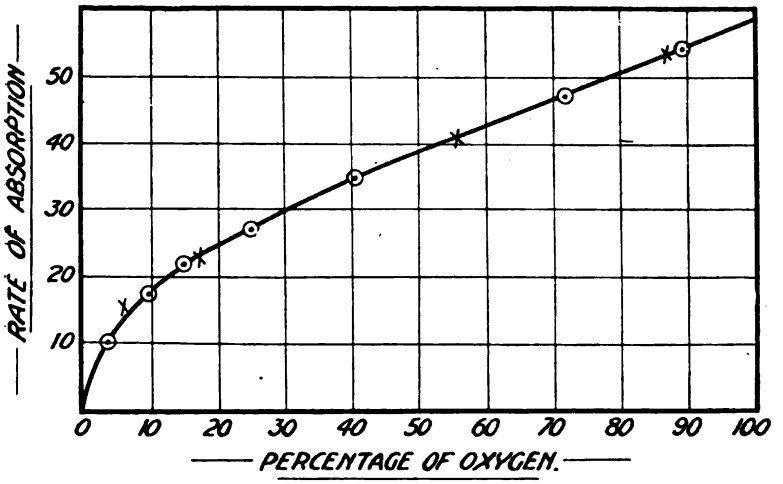
*Effect of Variation in the Oxygen Percentage in the Air on the Rate of Absorption.*—It is to be expected that a reduction of the percentage of oxygen in the air will also reduce the rate of absorption by the coal. It has been shown previously that the effect produced on the absorption is not directly proportional to the reduction in oxygen percentage, for, when the oxygen percentage in the air was reduced to 8, the rate of absorption was still 65 per cent. of that in normal air containing 20·9 per cent. of oxygen.*

This experiment was made on "fresh" coal, so further tests have been made in order to see whether similar results are obtained with coal which has been exposed to the air for some time.

The samples used were first heated *in vacuo* to 85° Cent. in order to remove all occluded gas, and were then exposed to a current of air for 96 hours at 30° Cent. in a bottle, the bottom of which was covered with 25 cubic centimetres of 7·5-per-cent. caustic-soda solution, so arranged as not to come into contact with the coal. After 96 hours the bottle was evacuated completely, and a mixture of oxygen and nitrogen in approximately the desired proportion was allowed to enter. The reservoir was kept in connexion with the bottle for about an hour, in order that the pressure and temperature might become steady. During the first 10 minutes the pressure in the bottle decreases very rapidly when air is allowed to enter after evacuation, but after an hour all traces of this effect have disappeared. The reservoir of the oxygen and nitrogen mixture was then shut off from the bottle, and a second tap opened to put the latter in connexion with a water-gauge. The absorption of oxygen by the coal in the bottle caused a steady fall in pressure, which could be observed on the gauge, of which readings were taken at short intervals for ¼ to ½ hour. A sample of air was then taken from the bottle in a vacuous sample-tube and analysed, the results of the analysis

* See *Trans. Inst. M. E.*, 1913, vol. xlvi., page 574.

giving the percentage of oxygen in the air of the bottle. Since no hydrocarbons were being given off by the coal, and as all carbon dioxide produced was being absorbed by the caustic-soda solution in the bottle, the water-gauge readings are proportional to the rate of oxygen absorption of the coal, at the oxygen percentage found by the analysis. The series of results with different oxygen-nitrogen mixtures are plotted on the curve shown in the text. From this curve the results given in Table V. are taken. The rates of absorption are expressed in arbitrary units, since comparative figures only were required.




CURVE SHEWING THE VARIATION OF RATE OF ABSORPTION OF OXYGEN BY COAL, WITH VARIATION IN OXYGEN PERCENTAGE.

TABLE V.—COMPARISON OF THE RATES OF ABSORPTION OF OXYGEN BY COAL PASSING THROUGH A 60-MESH SIEVE FOR DIFFERENT OXYGEN PERCENTAGES. TEMPERATURE, 30° CENT.; BAROMETER, 760 MILLIMETRES.

| Percentage of oxygen in air. | Comparative rate of absorption of oxygen. |
|---|---|
| 5 | 12 |
| 10 | 18 |
| 15 | 22 |
| 21 (normal air) | 25½ |
| 40 | 34 |
| 60 | 42 |
| 80 | 50 |
| 100 | 58 |

A similar series of measurements were made on coarse coal passing a 2-mesh but left on a 10-mesh sieve. Expressed in arbitrary units, the rates of absorption showed exactly the same

variation as with the fine dust. The experimental points are marked with a cross on the curve.

The effect of reducing the oxygen percentage in the air is to reduce the rate of absorption of oxygen by the coal, but this reduction is not one of simple proportion. Thus the percentage has to be reduced to 5 before the rate falls to half that in normal air. Any moderate decrease affects the rate of absorption very little; consequently, it is obvious that it is not of the least use to reduce the oxygen percentage in the mine air to a point at which lights will still burn in the hope thereby to reduce in any marked degree the occurrence of spontaneous heatings.

Whilst the connexion between the oxygen percentage and the rate of absorption is not one of simple proportion, there is a simple relation between the two—namely, the rate of oxidation is proportional to the square-root of the oxygen percentage in the air. If $A$ = the rate of absorption, $P$ = the percentage of oxygen, and $K$ = a constant: then—

$$A = K\sqrt{P};$$

$$\text{or } \frac{A}{\sqrt{P}} = K.$$

That this relation expresses the results fairly well is shown by the values of $K$ as tabulated below:—

| Percentage of oxygen. | $K$. | Percentage of oxygen. | $K$. |
|---|---|---|---|
| 5 | 54 | 40 | 54 |
| 10 | 57 | 60 | 54 |
| 15 | 57 | 80 | 56 |
| 21 | 56 | 100 | 58 |

For a simple chemical reaction the rate of absorption would probably be proportional to the oxygen percentage or to some higher power of it. No definite meaning can be given to the fact that the absorption is proportional to the square-root of the oxygen percentage. Since, however, the absorption is complicated by the number of substances in the coal which possibly take part in the reaction, and also by the physical structure of the coal itself, it is probable that the relation $A = K\sqrt{P}$ is only an approximation to a more complex equation. It nevertheless expresses the results with some accuracy, and, whatever the actual mechanism of the reaction may be, from a practical point of view the measured rate of absorption is the important factor, since this controls the rate of heat-production by the coal. The

importance of keeping goaves, or other areas liable to spontaneous heating, airtight becomes very evident. A small leak into such an area which suffices to keep the oxygen percentage at 5 will keep the spontaneous generation of heat at half what it would be in normal air. No place (in a mine liable to gob-fires) in which the oxygen ever rises above 2 per cent. should be considered properly stowed off and not liable to heating. So long as the oxygen is below 2 per cent., it would seem that no coal has a sufficiently high rate of oxidation to cause any serious rise in temperature.

# THE ATMOSPHERIC OXIDATION OF IRON PYRITES.

BY T. F. WINMILL, B.A., B.Sc., DONCASTER COAL-OWNERS' LABORATORY.

*Introduction.*—Among the various theories proposed to account for the spontaneous ignition of coal, one which has at times been very strongly held is that the initial heating is due to the oxidation of iron pyrites. That this is not generally the case has been shown by previous papers from this laboratory,* which have proved that the atmospheric oxidation of coal itself is quite sufficient to explain the nature and origin of gob-fires without the intervention of any other substance. Although this is undoubtedly the case in many instances, it is yet possible that in others pyrites may be a contributory factor to the initial heating. At the outset much very contradictory evidence is met with. In South Yorkshire, for example, pyrites is commonly found with the coal, either in large and heavy lumps, or in very thin bright yellow veins. Such pyrites may be kept exposed to the air for several years without the brightness of the surface being dimmed or the most delicate tests detecting any sign of oxidation. Pyrites in this highly crystalline form is obviously not concerned in the spontaneous heating of coal. On the other hand, lumps of inferior coal, associated with some seams, especially some in North Staffordshire, when exposed to the air for a few months, disintegrate completely, and fall to a greyish mass of ferrous sulphate and coal-dust, leaving no possible doubt of the very considerable oxidation of pyrites which has occured. Many seams in which oxidation of pyrites is evident are notoriously subject to gob-fires, and it is not unreasonable to connect the two facts, and to suppose that the presence of pyrites is the determining factor. In view, however, of the totally different behaviour of the pyrites in South Yorkshire, where the coal and not the pyrites is to be held responsible for heatings, some samples of North Staffordshire coals have been examined.

* See more especially *Trans. Inst. M. E.*, 1914, vol. xlviii., page 535.

Despite the fact that the seams from which they were taken were liable to fire, the coals proved to be among the least oxidizable of any, indicating that in this particular district the pyrites might have some considerable share in the heating. In order to settle this point, the atmospheric oxidation of pyrites has been examined in some detail.

Iron pyrites, when free, of course, from foreign matter, is a definite chemical compound of iron and sulphur, represented by the formula $FeS_2$. It has been known for a very long time that this compound on exposure to the air might undergo considerable oxidation, with the production of heat and the formation of ferrous sulphate and sulphuric acid; in fact, this reaction was at one time the main source of concentrated sulphuric acid. The changes taking place may be represented by the following equation:—

$$2FeS_2 + 7O_2 + 2H_2O = 2H_2SO_4 + 2FeSO_4 \quad . \quad . \quad . \quad . \quad (1)$$

in which the formation of ferrous sulphate and no ferric sulphate is supposed to occur. If the latter compound is formed, the equation becomes:—

$$4FeS_2 + 15O_2 + 2H_2O = 2Fe_2(SO_4)_3 + 2H_2SO_4 \quad . \quad . \quad . \quad (2)$$

This reaction does not take place to any considerable extent until all the pyrites has disappeared, for ferric sulphate in a slightly acid solution to which pyrites has been added is fairly quickly reduced to ferrous sulphate, although the reduction is not complete. The reaction is a complex one, in which some free sulphur is produced. Equation (1) may be taken as representing the main reaction when pyrites is oxidized at a moderate temperature. When, however, the temperature is raised to anything approaching a red heat, the final products are quite different, sulphur dioxide and ferric oxide being produced, according to the equation—

$$2FeS_2 + 11O = Fe_2O_3 + 4SO_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

But this reaction has, of course, no importance from the point of view of the origin of spontaneous heating, since it will only occur when the whole mass is red hot.

*Heat produced by the Atmospheric Oxidation of Pyrites.*—If pyrites is to exert any considerable effect on the spontaneous heating of coal, it must produce a considerable quantity of heat during its oxidation. No direct measurement of this quantity has been made until now; but, from the known heats of com-

bustion of iron and sulphur, an approximate value was calculated by Messrs. Haldane and Meachem.* The data then available were very incomplete, and a result, admittedly too high, of 4·5 calories per cubic centimetre of oxygen absorbed was obtained.

Later Sommermeier† determined the heat of combustion of pyrites to ferric oxide and sulphur dioxide accordingto equation (3), and from this the heat of formation of pyrites can be calculated. Using this result, Messrs. Parr and Kressmann calculated a value for the atmospheric oxidation of pyrites of 4·1 calories per cubic centimetre of oxygen absorbed. Owing to their somewhat indirect method of calculation, it is doubtful exactly what this result means. Thus they state that "no account is made in this calculation of the heat of hydration of ferrous sulphate,"‡ and yet in their fourth equation the heat of formation used is that of the hydrated salt, and their final result must therefore include the heat of hydration of ferrous sulphate. When reduced to a simpler form, in which the meaning of the quantities used is more obvious, the calculation may be put as follows:—

Sommermeier finds—

$$2FeS_2 + 11O = Fe_2O_3 + 4SO_2 + 373K \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $K$ is the large calorie and equals 1,000 small centigrade calories. The heat of formation of pyrites from this equation is equal to ½ (heat of formation of $Fe_2O_3$ + 4 times the heat of formation of $SO_2$ less $373K$) = ½ $(198 + 4 \times 70 - 373) = 52{\cdot}5K$.

All the heats of formation of the substances in equation (1) are now known, and the heat produced in the reaction will be the sum of the heats of formation of the substances on the right-hand side of the equation, less the similar sum of those on the left-hand side. The values for these quantities are:—$FeS_2 = 52{\cdot}5K$; $H_2O$ (liquid) $= 69{\cdot}0K$ (Berthelot); $FeSO_4\,7H_2O = 240K$ (Le Chatelier); and $H_2SO_4$ (concentrated liquid) $= 193K$ (Thomson).

Hence the heat of reaction—

$$= (2 \times 240 + 2 \times 193) - (2 \times 52{\cdot}5 + 2 \times 69) = 623K;$$

that is, the absorption by pyrites of 7-pound molecules (or 224

* *Trans. Inst. M. E.*, 1898, vol. xvi., page 457.

† "Forms in which Sulphur occurs in Coal; their Calorific Values and their Effects upon the Accuracy of the Heating Powers, calculated by Dulong's Formula," by E. E. Sommermeier, *Journal of the American Chemical Society*, 1904, vol. xxvi., page 566.

‡ *University of Illinois Bulletin*, 1910, vol. viii., No. 16, page 33.

pounds) of oxygen is sufficient to raise 623,000 pounds of water 1 degree centigrade in temperature; or, otherwise expressed, 1 cubic centimetre of oxygen absorbed by pyrites produces 4 calories.

This calculation is, of course, based on the assumption that nothing but pyrites, water, and oxygen is concerned in the reaction, and that the water is used only to hydrate the ferrous sulphate, and not to dilute the sulphuric acid. As a rule, however, sufficient water will be present to cause considerable dilution of the acid, and sufficient carbonates will also be present to neutralize this free acid. Whether dilution of the acid takes place or not, if the acid is neutralized with, say, calcium carbonate, the quantity of heat produced is equal to the sum of the heat of dilution of the acid, and the heat of reaction of the dilute acid with the carbonate, and amounts to 43 calories. If no ferric salts are produced, then the oxidation of pyrites *in situ* will produce about $666K$, or 4·3 calories per cubic centimetre of oxygen absorbed. If ferric salts are produced to any extent, this quantity of heat would be increased, but probably only to a very slight extent. Thus the equation for the complete oxidation of pyrites in the presence of a carbonate would be as under:—

$$2FeS_2 + 15O + 4CaCO_3 = Fe_2O_3 + 4CO_2 + 4CaSO_4;$$

and the heat produced by the reaction would be $671K$, or almost the same as for the previous reactions in which the oxidations stopped at the ferrous stage.

As a check on the assumptions involved in these calculations, a direct determination of the heat evolved during the oxidation has been made, somewhat on the lines of the similar experiment with coal.* A quantity of pyrites was placed in a vacuum-flask, a measured quantity of oxygen admitted, and the rise in temperature (usually about 50° Cent.) noted. The experiment was usually started at 40° Cent. So as to avoid loss of heat from the vacuum-flask, the bath in which it was immersed was heated at a rate which kept its temperature 1° Cent. behind that of the contents of the flask. The measurement of the quantity of oxygen absorbed was checked by determining the quantity of sulphate produced by the oxidation. The results obtained were not very concordant, the mean being 4·5 calories, with an error of $\pm 0{\cdot}3$ calorie. They, however, confirm the results of the cal-

* See *Trans. Inst. M. E.*, 1914, vol. xlviii., page 508.

culations, and the best value for the oxidation under conditions such as exist in a mine would seem to be 4·3 calories per cubic centimetre of oxygen absorbed.

The heat produced by the oxidation of pyrites is, therefore, twice that produced by the absorption of a similar quantity of oxygen by coal. Owing to this fact, and the lower specific heat of pyrites, which is only about two-thirds that of coal, the same oxygen absorption in both cases would raise the temperature of pyrites three times as much as it would that of an equal weight of coal. Since the heat production is so large, it becomes of importance to know the rate of oxidation of pyrites, as if this rate approaches that of coal, the former will evidently be a possible cause of heating.

*Rate of Oxidation of Pyrites.*—The rate of oxidation was determined in the manner previously described for coal oxidations, at 30° Cent. The results of the measurements are set forth in Table I.

The figures tabulated in columns A and C refer to two different samples of pyrites, one of which (C) shows in the mass no sign of oxidation when exposed to the air for a considerable time, whilst the other (A) in similar circumstances readily becomes coated with ferrous sulphate. When reduced to dust, however, the rates of oxidation of the two samples are very much the same. The reason for this apparent contradiction is given by columns B and D, in which the coarse pyrites from Staffordshire is shown to have about 17 times as great a rate of oxidation as the South Yorkshire sample (D). Whilst, therefore, as might be supposed from the same chemical substance, the two samples have much the same rate of oxidation under identical conditions, in practice these conditions never become identical. The South Yorkshire pyrites usually occurs in large masses of a very highly crystalline form, and in this condition undergoes very little oxidation indeed, partly owing to the relatively small surface exposed, and partly owing to the nature of that surface, which consists entirely of unbroken crystal faces. Now, it is well-known that a crystal face may be much more resistant to chemical action than the interior of the crystal, and it seems evident that this resistance to oxidation is developed to a high degree at a crystal face in pyrites. When the crystal is broken, the figures under column C show that

oxidation takes place readily. Some such hypothesis must be adopted to explain the non-oxidation of " brass " in the mass, and its ready oxidation in the form of dust.

TABLE I.—RATE OF OXIDATION OF PYRITES IN CUBIC CENTIMETRES PER 100 GRAMME-HOUR AT 30° CENT.

*Sample A.*

Ground to pass a 60-mesh sieve. The sample contained 81·3 per cent. of pyrites, the remainder being coaly matter. The results have been corrected to represent 100 per cent. of pyrites.

*Sample B.*

Ground to pass a 10-mesh but not a 30-mesh sieve. Contained 80 per cent. of pyrites. The results have been corrected to represent 100 per cent. of pyrites.

Samples A and B are both from a North Staffordshire seam.

*Samples C.*

Ground to pass a 200-mesh sieve. Contained 98 per cent. of pyrites.

*Sample D.*

Part of same sample as C, but ground to pass a 10-mesh, and left on 30-mesh sieve.

Samples C and D were from the Barnsley seam.

| Hours. | Oxygen absorbed, in cubic centimetres, per 100 gramme-hour. | | | |
|---|---|---|---|---|
| | A. | B. | C. | D. |
| 2 | 31·5 | 15·5 | 25·6 | 1·6 |
| 4 | 23·6 | 13·5 | 17·3 | 1·2 |
| 6 | 19·7 | 12·8 | 15·1 | 0·9 |
| 8 | 16·9 | 12·4 | 13·8 | 0·75 |
| 12 | 13·9 | 11·9 | 12·0 | 0·65 |
| 18 | 11·8 | 11·1 | 10·3 | 0·60 |
| 24 | 10·8 | 10·4 | 9·4 | 0·55 |
| 30 | 9·7 | 9·9 | 8·8 | 0·50 |
| 36 | 9·3 | 9·5 | 8·4 | — |
| 48 | 9·0 | 8·8 | 8·0 | 0·45 |
| 60 | 8·8 | 8·3 | 7·8 | — |
| 72 | 8·75 | 7·8 | 7·6 | — |
| 96 | 8·65 | 7·0 | 7·2 | 0·40 |
| 120 | 8·5 | — | 6·9 | — |
| 144 | 8·35 | — | 6·5 | — |
| 168 | 8·2 | — | 6·0 | — |
| Total oxygen absorbed in 96 hours, in cubic centimetres ... ... | 1,065 | 853 | 913 | 53 |
| ,, ,, in 168 hours | 1,670 | — | 1,388 | — |

The readily oxidizable North Staffordshire pyrites is in a very different physical state from the South Yorkshire " brass," which is most commonly found in isolated lumps, whilst the former is usually mixed intimately with coal. Often this mixture will be quite black, and, except for its weight, not readily

distinguishable from a "dirty" coal free from pyrites. When the percentage of pyrites is very high, it appears to be to some extent crystallized, and the lump presents a dull grey appearance. In the selection of samples A and B all foreign matter was removed by chipping until the lumps (about ½-inch cubes) had a uniformly grey surface. They were even then far from being pure pyrites, as is shown by the analyses recorded in Table I., and in the powdered form had a density much lower than the powdered "brass."

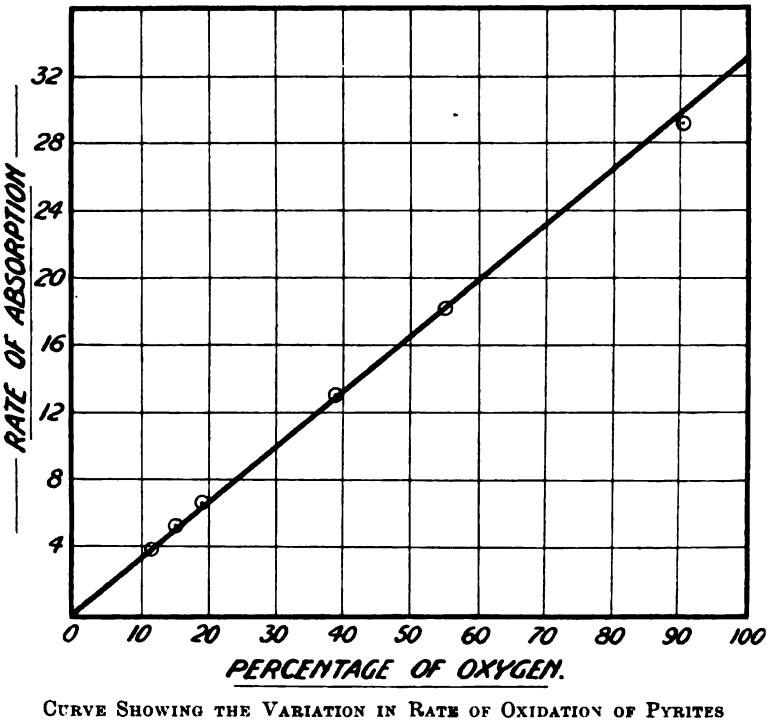
South Yorkshire "brass," 98 per cent. of $FeS_2$; density = 4·73.
North Staffordshire pyrites, 81 „ „ ; „ = 3·11.

A mixture of 81 parts of the first sample with 19 of coal (density, 1·3) to correspond in composition with the second sample would have a density = 3·15, which is not very different from the figure found for the second sample. Now, the 19 parts of coal would occupy a volume of 14·6, while the 81 parts of pyrites would have a volume of 17·1. In other words, the pyrites is distributed through nearly twice the volume that it would have if pure. There is, then, a very great physical difference between the compact and highly crystalline "brass" and this pyrites disseminated through coal. It must be supposed that in the latter state the pyrites occurs in very fine particles in a porous medium, and that air will, therefore, be able to reach a far larger surface than is represented by the nominal size of the particles. This renders intelligible the results set forth in Table I. in columns A and B, which show that the coarse pyrites which will just pass a 10-mesh sieve has a rate of oxidation of 80 per cent. of that passing a 60-mesh sieve, although the nominal ratio of the exposed surfaces is at least 6.

The general shape of the oxidation-time curves for pyrites is not unlike that of the oxidation-time curves for coal, but the former show a less marked fall with time. Whereas in the case of coal the absorption falls to about 7 per cent. of the initial in a week, that of pyrites only falls to about 25 per cent. in the case of the fine dust. With the coarser dusts the difference is even more marked, for in 96 hours the absorption rate falls to 45 per cent. for pyrites, as against a fall to 9 per cent. for coal of similar size.

The decrease in the rate of oxidation with time seems to be due to the formation of ferrous sulphate on the surface of the

particles of pyrites, which would, of course, prevent the ready access of oxygen. After sample B had been oxidized at 30° Cent., it was washed very thoroughly with dilute hydrochloric acid in an apparatus from which air was excluded, dried as completely as possible on blotting-paper, and the rate of oxidation redetermined at 30° Cent. It showed a rate of oxidation of 13·0 and 11·6 respectively at the end of the second and fourth hours, as compared with a rate of 15·5 and 13·5 on the original sample. With the removal of the products of oxidation, the activity is very largely restored.




Curve Showing the Variation in Rate of Oxidation of Pyrites with Variation of Oxygen Percentage.

From a comparison of columns C and D, which refer to practically pure pyrites, it appears that the rate of oxidation is proportional to the surface exposed, for sample C has about 20 times the surface of sample D, and the rate of oxidation is about 18 times as fast.

The increase of the rate of oxidation with temperature is very rapid, as the following measurements in Table II. will show:—

Table II.—Comparison of Rate of Oxidation of Pyrites at different Temperatures.

| Temperature. Degrees Cent. | Rate of oxidation. |
|---|---|
| 30 | 6·8 |
| 40 | 13·6 |
| 50 | 27·8 |
| 60 | 57·1 |

A rise of 10° Cent. in temperature doubles the rate of oxidation. The effect of a change in the oxygen percentage was measured by the same method as that previously described for similar experiments with coal. With pyrites no rapid initial change in pressure is noticed immediately after air has been admitted to the evacuated bottle. The results are recorded in Table III.

Table III.—Effect of Oxygen Percentage on Rate of Oxidation of Pyrites.

| Percentage of oxygen. | Rate of absorption. |
|---|---|
| 10·6 | 3·63 |
| 14·0 | 5·29 |
| 18·5 | 6·5 |
| 38·4 | 13·0 |
| 55·0 | 18·1 |
| 89·0 | 29·2 |

These experimental points are shown in the figure in the text, from which it appears that the curve connecting them is a straight line, which obviously means that the rate of oxidation is directly proportional to the percentage of oxygen in the air.

The oxidation of pyrites differs, therefore, in some respects from the oxidation of coal, and these differences arise from the fact that the former is a simple chemical reaction, whilst the latter is a very complex one. The rate of oxidation of pyrites, in the pure state, is affected much more by the size of the particles than is the oxidation of coal. Whether the pyrites be free, or mixed with coal, reduction of the percentage of oxygen in the air reduces the oxidation of the pyrites much more than it reduces the oxidation of coal. For example, if the oxygen percentage in the air is 5, the rate of oxidation of coal is halved, whilst that of pyrites is reduced to a quarter of the rate in normal air. An increase in temperature causes a somewhat greater increase in the oxidation of pyrites than it does in the case of coal.

*Conclusions.*—From the results described in this paper, it is possible to calculate roughly the rate of spontaneous heating of a

specimen of finely-divided pyrites, on the assumption that all the heat developed is used in raising the temperature of the pyrites, and that none is lost. Very approximately the rate of increase works out as follows:—

| | Degrees Cent. |
|---|---|
| Initial temperature ... ... .. ... ... | 30 |
| After 1 hour, the temperature rises to ... ... ... | 40 |
| ,, 2 hours, ,, ,, ,, ... ... ... | 55 |
| ,, 3 hours, ,, ,, ,, ... ... ... | 90 |

If we make the same assumptions, and start with the same initial temperature, the same rise in temperature with an average oxidizable coal would take 48 hours. It is clear, therefore, that where finely-divided pyrites occurs in considerable proportion among coal, it may be the chief factor in originating combustion. It has been stated that small heaps of coal left at the face have been known to fire in 24 to 48 hours in North Staffordshire, a statement which is quite intelligible if pyrites originated the heating, but not if coal alone is held responsible.

In considering the heating effect of pyrites, a careful distinction must be drawn between the rate of heating of pure finely-divided pyrites and the effect of a moderate quantity of pyrites mixed intimately with coal. The rapid increase in temperature of pure pyrites is due partly to its low specific heat, and partly to the rapid increase in the rate of oxidation with rising temperature. If sufficient foreign matter be mixed with the pyrites to minimize the initial rise in temperature, the rate of increase is very considerably decreased. Thus, if 10 per cent. of finely-divided pyrites be added to Barnsley Hard coal, and the mixture carefully heat-insulated and allowed to absorb oxygen, the temperature could rise 10·6° Cent. in seven hours, whilst the Barnsley Hard coal by itself would under the same conditions rise 10° Cent. The effect of adding 10 per cent. of pyrites is very small indeed. Pyrites, therefore, can only be the cause of a heating when it is present in considerable proportion, and in a very finely-divided state. In order to equal the effect of a normal oxidizable coal, about 30 per cent. of pyrites must be present if the coal with which it is mixed has so small a rate of oxidation that by itself it is not liable to fire. If the pyrites occurs in lumps, or veins, in the form of the highly crystalline "brass," it contributes nothing to the initial heating.

# THE ABSORPTION OF OXYGEN BY COAL.

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## Part IX.—Comparison of Rates of Absorption of Oxygen by Different Varieties of Coal.

*Introduction.*—The previous papers from this laboratory have been concerned only with the atmospheric oxidation of coals from the Barnsley Seam, and for these coals much information has been obtained as to the rate and magnitude of the oxidation. It has been shown that, so far as the Barnsley Seam is concerned, an adequate explanation of the origin and nature of gob-fires can be given, based on the reaction between the coal itself and the oxygen of the air, without the intervention of any other substance. It becomes of importance, therefore, to ascertain how far a similar explanation will hold good for spontaneous heating in other seams, and with this object in view samples have been taken from a considerable number of pits in different parts of the country, some liable to fire, and others not liable.

*Collection of Samples.*—A sample of coal of which the oxidation is to be measured must be protected from oxidation, as far as possible, from the moment it is taken until the measurements are made. Neglect of this obvious precaution will make the measurements meaningless. In these circumstances it becomes very difficult indeed to take a true average sample of a seam, and no attempt has been made, therefore, to obtain anything more than a typical sample. By the kindness of the managements of the mines visited, it was always possible to go to several working-places, and to inspect the general conditions in the seam or seams, and then to take a compact lump of coal about 7 pounds in weight from whatever place was selected. The lump was always taken from a regularly advancing face, and a foot or two behind it, in a section free from breaks. The sample was then brought to the surface, and the outside sections split off with a hammer and chisel, so as to get about 2½ pounds from the centre of the block. This was then broken into convenient pieces and at once

put into a bottle closed by a glass stopper, which by an outside screw seated firmly on to a rubber ring. Such bottles are sold very cheaply for making preserves, and experience shows that they are quite airtight and very suitable for taking samples of coal. They are capable of withstanding any pressure set up by the evolution of gas from the most gassy coals. The main part of the sample was in 1½-inch cubes, but part of the space between these pieces was filled with coal-dust, in order that the oxygen from the air remaining in the bottle might be absorbed quickly without affecting the larger pieces. Only the latter were ground up for the measurements of the rate of oxidation.

*Analysis of Coal Samples.*—A complete analysis of each sample was made as soon as possible after grinding, usually within 24 hours. Until the analysis was started, the ground sample was kept in a small airtight bottle completely filled with the dust. The percentages of carbon and hydrogen, and of any other constituent which amounted to more than 3 per cent., were determined on dust which had been dried *in vacuo*. Smaller percentages were determined on the undried dust, and the results of the analyses are, of course, calculated on the basis of the coal before drying.

The advantages of determining the chief constituents of the coal on a sample which has been dried *in vacuo* are obvious; the results are not affected by any uncertainty in the quantity of moisture or the presence of occluded gases. When, however, dried coal is used for an analysis, very great care must be taken to avoid the reabsorption of moisture. It has been found best to weigh all vessels containing dried coal inside a second airtight vessel which contains powdered caustic potash. No increase in weight by reabsorption of moisture takes place under these conditions. The drying of the coal for analysis must, of course, be done either *in vacuo* or in a current of inert gas. To dry coal at over 100° Cent. in air, as is the usual practice, before determining the percentage of carbon and hydrogen, gives utterly untrustworthy results, as is shown in a previous paper.*

The quantity of moisture in the samples of coal was determined by the vacuum method already described, the nitrogen by Kjeldahl's method, and the sulphur by Eschka's method of

* *Trans. Inst. M. E.*, 1916, vol. li., page 484.

ignition with magnesium oxide and sodium carbonate, and subsequently with a small quantity of ammonium nitrate.

*Results of Analyses.*—These are all calculated on the basis of the coal containing the natural percentage of moisture, but free from occluded gases. Where the percentage of sulphur is high, some allowance has to be made for the replacement of the sulphur in the ash by oxygen. Thus, if the sulphur is all present as iron pyrites, when the coal is completely reduced to ash a quantity of oxygen will be retained in the ash in place of the sulphur, according to the following equation:—

$$2FeS_2 + 11O = 4SO_2 + Fe_2O_3;$$

that is, the ash has taken up oxygen which was not one of its original constituents. Since the percentage of oxygen in coal can only be determined by difference, the introduction of this oxygen into the ash must be allowed for. If all the sulphur were present in the coal as pyrites, the correction would be simple. To the percentage of oxygen as determined by difference, three-eighths of the percentage of sulphur found should be added. There is no doubt, however, that all the sulphur in coal is not present as pyrites. How much is present in other forms it is difficult to decide. In some coals containing 1 per cent. or less of sulphur, only very small traces of iron have been found. Further, pyrites when burnt leaves a weight of ferric oxide five-fourths as large as the weight of sulphur present. In some cases the total ash of the coal sample is less than five-fourths of the sulphur content (*cf.* especially Table VI.), which cannot therefore be due to pyrites alone. As an approximation, no addition to the percentage of oxygen by difference has been made when the sulphur content does not exceed 1 per cent.; above this amount three-eighths of the excess has been added to the oxygen percentage in order to correct for the replacement of sulphur by oxygen in the ash.

*Measurement of Oxygen Absorbed.*—The oxygen absorbed has been measured, as described in previous papers, by passing a measured current of pure air through coal-dust kept at a constant temperature, and analysing the air after its passage through the dust. The samples were all ground to pass a 60-mesh sieve, and of such dust about 75 per cent. passed a 90-mesh and 50 per cent. a 200-mesh sieve. All samples have had their absorption measured at 30° Cent., and on some measurements have been

made at 60° Cent., so as to give some idea of the rate of variation of absorption with temperature, as this, of course, is of great importance in deciding whether the coal is liable to heat spontaneously.

In order to distinguish between the oxygen absorbed by any pyrites in the coal and that absorbed by the coal itself, a determination of the sulphate present in the sample before and after oxidation has been made. The difference between the two quantities of sulphate is a measure of the oxygen absorbed by pyrites, as calculated from the following equation:—

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4;$$

from which, the sulphate contained in 1 gramme of barium sulphate is produced by 167 cubic centimetres of oxygen.

The accuracy of this estimation of sulphates in the presence of coal was tested in the following way:—Some fine coal-dust free from sulphate and pyrites was mixed intimately with an accurately-weighed quantity of strong sulphuric acid, and the mixture exposed to the air for a week at 30° Cent. The coal was then extracted repeatedly with hot dilute hydrochloric acid until the last extract was free from sulphate. About 3 litres of extract per 100 grammes of coal are necessary to remove all the sulphate. The aqueous solution was then evaporated to a convenient bulk and the sulphate estimated in the usual manner. The results show that a sufficiently accurate determination can be made in this way:—

| | Grammes. |
|---|---|
| Quantity of strong acid added ... ... | = 1·2653; |
| Which contained ... ... ... ... | 1·2051 of $H_2SO_4$. |
| Quantity of $BaSO_4$ obtained ... ... ... | = 2·8292; |
| Which is equivalent to ... ... ... | 1·1887 of $H_2SO_4$. |

The quantity of oxygen absorbed by a specimen of pyrites containing about 20 per cent. of coal, of which the absorption was known, was then measured, and the sulphate produced by the oxidation was estimated as described:—

Total quantity of oxygen absorbed by the pyrites (measured at 0° Cent. and 760 millimetres barometer)=2,960 cubic centimetres.

Quantity of $BaSO_4$ produced=16·88 grammes, which is equivalent to 2,820 cubic centimetres of oxygen; that is, the oxygen absorption calculated from the sulphate produced is 95 per cent. of the measured absorption.

In determining the sulphate produced by the oxidation of pyrites mixed with coal, it is essential that the mixture should be very thoroughly extracted with boiling dilute hydrochloric acid, and, of course, that air should be excluded during the extraction. Unless these precautions are taken, much less sulphate than corresponds to the oxygen absorption will be found.

The figures given in the following tables all refer to the rate of absorption measured in cubic centimetres per 100 grammes of coal in 1 hour. No allowance has been made, in calculating the absorptions, for ash or moisture in the coal, so that the figures relate directly to the analyses given for the sample. For convenience of comparison, the total quantity of oxygen absorbed in 96 hours has been calculated in each case.

To serve as a basis for comparison, the rates of oxidation of the coals from the Barnsley Seam in the Doncaster area may be considered first. In this district there remains little doubt that the atmospheric oxidation of the coal itself is the cause of gob-fires, and that pyrites in the form in which it occurs there has no influence in promoting combustion. Any other coals, therefore, which have an oxidation similar to the Barnsley coals should also be liable to fire from similar causes. As to whether two similarly oxidizable coals from different pits do fire equally readily in the pit depends, of course, on the conditions under which the coal is found and is worked. It has been shown that those factors that particularly favour spontaneous heating are the regulation of the air-supply and the state of division of the coal. Conditions which cause breaks in the coal, falls at the face, and the leaving of any considerable amount of small coal, or coal which becomes crushed small, in the goaf, will assist the starting of a fire; whilst, if all these conditions are absent, the initiation of a fire will become difficult or impossible. Two coals having equal oxidations will be equally *liable* to fire if the conditions are identical. Where in practice two equally oxidizable coals do not both fire in the pit, it will mean that in the one case working conditions are such as to prevent or avoid circumstances which favour spontaneous heating.

In Table I. are set forth the rates of oxidation of Barnsley Hard coal from five different pits, together with the analyses of the coals.

TABLE I.—RATE OF OXIDATION OF BARNSLEY HARD COAL AT 30° AND 60° CENT.

| Mine. | A. | B. | C. | D. | E. | A. |
|---|---|---|---|---|---|---|
| Sample No. | 24 | 25 | 26 | 27 | 28 | 24 at 60° Cent. |
| Rate after hours. | | | | | | |
| 2 | | 20·0 | | 18·0 | 15·0 | 66·0 |
| 4 | | 14·9 | | 11·3 | 10·1 | 38·2 |
| 6 | | 11·8 | | 7·5 | 7·2 | 27·7 |
| 8 | | 9·7 | | 6·4 | 5·7 | 22·7 |
| 12 | | 7·2 | | 5·1 | 5·3 | 17·7 |
| 18 | | 5·6 | | 3·9 | 4·2 | 13·7 |
| 24 | | 4·8 | | 3·2 | 3·6 | 11·4 |
| 30 | | 4·1 | | 2·9 | 3·2 | 9·9 |
| 36 | | 3·7 | | 2·7 | 2·9 | 8·9 |
| 48 | | 3·2 | | 2·3 | 2·6 | 7·5 |
| 60 | | 2·7 | | 2·0 | 2·25 | 6·6 |
| 72 | | 2·3 | | 1·8 | 2·00 | 6·0 |
| 96 | | 1·9 | | 1·5 | 1·65 | 5·2 |
| Total absorbed in 96 hours, in cubic centimetres .. | | 453 | | 327 | 340 | 1,150 |

No sulphate was produced in any of the above oxidations; hence pyrites played no part in them.

ANALYSES OF COALS.

| Mine. | A. | B. | C. | D. | E. |
|---|---|---|---|---|---|
| Sample No. | 24. | 25. | 26. | 27. | 28. |
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Moisture .. .. | 9·55 | 8·39 | 8·41 | 5·06 | 4·60 |
| Ash .. .. | 3·40 | 3·92 | 2·59 | 3·21 | 5·91 |
| Carbon .. .. | 71·80 | 72·87 | 73·69 | 75·67 | 74·82 |
| Hydrogen .. .. | 4·48 | 4·50 | 4·52 | 4·69 | 4·67 |
| Nitrogen .. .. | 1·30 | 1·37 | 1·29 | 1·06 | 0·95 |
| Sulphur .. .. | 0·83 | 0·70 | 0·78 | 0·84 | 0·78 |
| Oxygen (by difference) | 8·64 | 8·25 | 8·72 | 9·47 | 8·27 |

In addition to the Hard coal, there are also soft coals, cannels, and jacks associated with the Barnsley Seam. The rates of oxidation of these are very similar to those for the Hard coal.* Samples of the Barnsley Softs have been taken as representing these other parts of the seams, with the results recorded in Table II.

Tables I. and II. show that all these coals have an oxidation of very much the same type, but that the most oxidizable coals, both softs and hards are from pits A, B, and C, and that the samples from pits D and E are distinctly less oxidizable. Of these five pits, the one least troubled with fire is D, despite the fact that the oxidation of the coal is as large as that from E.

* See *Trans. Inst. M. E.*, 1913, vol. xlvi., page 563; and 1914, vol. xlviii., page 521.

The reason for the freedom from trouble in the former case lies in the different working conditions. Less coal is left behind, and the roof is said to be less liable to fracture, making falls less frequent and the goaf more airtight; in addition, fewer faults are met with. The presence of faults in a seam liable to fire very readily sets up just those conditions most favourable to heating, owing to the difficulty of getting the goaf airtight on the fault side, both on account of the uneven subsidence and of the occurrence of falls.

Of the three pits A, B, and C, A and B have had many more fires than C, probably owing to the fact that in the setting-out of C features which were known to have caused trouble at A and B were largely avoided. In faulty ground heating occurs as readily in C as in A or B.

TABLE II.—RATE OF OXIDATION OF BARNSLEY SOFTS AND CANNEL AT 30° CENT.

| Mine. | A. | C. | D. | E. | A. |
|---|---|---|---|---|---|
| Sample No. | 29. | 30. | 31. | 32. | 23 (cannel). |
| Rate after hours. | | | | | |
| 2 | 21·7 | 19·0 | 15·0 | 15·0 | 17·3 |
| 4 | 16·8 | 15·0 | 9·5 | 9·5 | 12·1 |
| 6 | 14·0 | 12·2 | 7·7 | 7·7 | 9 6 |
| 8 | 12·0 | 10·5 | 5·0 | 5·0 | 8·1 |
| 12 | 9·3 | 8·5 | 3·5 | 3·5 | 6·2 |
| 18 | 7·0 | 6·5 | 3·0 | 3·0 | 4·8 |
| 24 | 5·5 | 5·2 | 2·6 | 2·6 | 4·0 |
| 30 | 4·6 | 4·3 | 2·4 | 2·4 | 3·5 |
| 36 | 4·2 | 3·8 | 2·3 | 2·3 | 3·1 |
| 48 | 3·6 | 3·4 | 2·1 | 2·1 | 2·6 |
| 60 | 3·2 | 2·9 | 2·0 | 2·0 | 2·3 |
| 72 | 2·8 | 2·6 | 1·9 | 1·9 | 2·0 |
| 96 | 2·3 | 2·1 | 1·7 | 1·7 | 1·7 |
| Total absorbed in 96 hours, in cubic centimetres .. .. | 516 | 475 | 311 | 311 | 374 |

No pyrites was oxidized in any of the above samples.

ANALYSES OF COALS.

| Mine. | A. | C. | D. | E. | A. |
|---|---|---|---|---|---|
| Sample No. | 29. | 30. | 31. | 32. | 23 (cannel). |
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Moisture .. .. | 9·79 | 10·00 | 4·34 | 3·30 | 6·60 |
| Ash .. .. .. | 2·07 | 2·15 | 2·29 | 1·32 | 4·39 |
| Carbon .. .. | 70·38 | 70·72 | 76·51 | 79·67 | 72·22 |
| Hydrogen .. .. | 4·81 | 4·77 | 5·01 | 5·10 | 5·46 |
| Nitrogen .. .. | 1·33 | 1·38 | 1·32 | 1·16 | 1·24 |
| Sulphur .. .. | 1·01 | 1·08 | 0·98 | 1·03 | 1·27 |
| Oxygen (by difference) | 10·61 | 9·80 | 9·55 | 8·42 | 8·82 |

In these five cases, then, the oxygen absorptions of the coals are in keeping with the liability to fire, as found by practical experience underground; these absorptions may therefore serve as a rough basis of comparison for other seams.

As examples of coals known to be free from the liability to spontaneous heating the anthracites and steam-coals of South Wales may be taken. The oxidations of two samples of anthracite are set forth in Table III.

TABLE III.—RATES OF OXIDATION OF ANTHRACITE UNDER VARYING CONDITIONS. Samples Nos. 14 and 14*a* from the Big Vein, South Wales; Sample No. 13 from the Peacock Seam, South Wales.

| Sample No. | 13 at 30° Cent. passing 60-mesh sieve. | 14 at 30° Cent. passing 60-mesh sieve. | 14*a* at 30° Cent. passing 2- and over 10-mesh sieve. | 14*a* at 60° Cent. passing 60-mesh sieve. |
|---|---|---|---|---|
| Rate after hours. | | | | |
| 2 | 18·1 | 23·0 | 2·07 | 50·0 |
| 4 | 10·0 | 15·2 | 1·72 | 18·0 |
| 6 | 7·25 | 12·0 | 1·5 | 12·2 |
| 8 | 6·0 | 9·8 | 1·3 | 9·9 |
| 12 | 4·5 | 7·0 | 1·1 | 5·7 |
| 18 | 3·2 | 4·7 | 0·9 | 3·9 |
| 24 | 2·6 | 3·4 | 0·8 | 3·2 |
| 30 | 2·2 | 3·0 | 0·7 | 2·8 |
| 36 | 1·9 | 2·6 | 0·65 | 2·4 |
| 48 | 1·5 | 2·2 | 0·60 | 1·7 |
| 60 | 1·3 | 1·8 | — | 1·4 |
| 72 | 1·1 | 1·55 | 0·55 | 1·1 |
| 96 | 0·8 | 1·1 | 0·50 | 0·4 |
| Total absorbed in 96 hours, in cubic centimetres .. .. | 272 | 381 | 75 | 450 |

No pyrites was involved in the above oxidations.

ANALYSES OF COALS.

| Sample No. | 13. Per cent. | 14. Per cent. |
|---|---|---|
| Moisture .. .. .. .. | 1·58 | 1·80 |
| Ash .. .. .. .. .. | 1·96 | 1·74 |
| Carbon .. .. .. .. .. | 89·20 | 88·85 |
| Hydrogen .. .. .. .. | 3·51 | 3·34 |
| Nitrogen .. .. .. .. | 1·16 | 1·16 |
| Sulphur .. .. .. .. .. | 0·75 | 0·81 |
| Oxygen (by difference) .. .. | 1·84 | 2·30 |

These two anthracites have an oxygen absorption in 96 hours at 30° Cent. as follows:—

| | Cubic centimetres. |
|---|---|
| Big Vein ... ... ... ... ... ... ... ... | 381 |
| Peacock ... ... ... ... ... ... ... ... | 272 |

The first of these absorptions is larger than those of the Barnsley Hards from pits D and E, which are liable to fire, and

yet anthracite has never been known to fire spontaneously. If, then, the oxygen absorption is a measure of the liability to fire, that of anthracite must be more considerably modified by different conditions than is the case for the Barnsley coals. The conditions which may affect the absorption most are: (1) the fineness of division; and (2) the variation of temperature.

If, therefore, the rate of absorption were more reduced for coarse anthracite-dust than for coarse dusts of other coals, this might afford some explanation of how it is that a high oxygen absorption does not cause the anthracite to fire. From Table III. it is clear that variation of absorption with fineness is much the same for anthracite as for other coals, and that it does not give any explanation of the anomalous oxygen absorption.

| | Through a 60-mesh sieve. | Through a 2- and over a 10-mesh sieve. |
|---|---|---|
| Oxygen absorbed in 96 hours by Barnsley Hards ... | 453 | 126 |
| ,, ,, ,, ,, anthracite ... ... | 381 | 75 |

The explanation lies with the variation in oxidation with temperature. From Table III. it appears that the quantity of oxygen absorbed by anthracite increases very little with rise of temperature, in comparison with other coals.

| | Cubic centimetres. | | Cubic centimetres. |
|---|---|---|---|
| Barnsley Hards at 30° Cent. ... | 453; at 60° Cent. | ... | 1150. |
| Anthracite at 30° ,, ... | 381; at 60° ,, | ... | 450. |

In 96 hours there is a slight increase in the absorption at 60° Cent., but this increase does not indicate that any new part of the coal-substance is undergoing oxidation. After about the twentieth hour, the absorption at 60° Cent. is lower than that at 30° Cent., falling at the ninety-sixth hour to one-third the rate at the lower temperature. The meaning of these figures is clear. The anthracite has a definite capacity for oxygen, and though this capacity is satisfied more quickly as the temperature rises, the total absorption is unaltered. In these circumstances the coal cannot possibly fire spontaneously. The total capacity for oxygen is little more than 450 cubic centimetres, and in absorbing this amount the coal would produce sufficient heat to raise its temperature about 30° Cent.—say from 30° to 60° Cent.—provided no heat were lost. When the coal had attained this temperature, its capacity for oxygen would be completely exhausted: it could produce no more heat, and consequently would cool off.

Whilst the anthracites show at 30° Cent. an oxygen absorption not very different from that of a coal liable to gob-fires, the samples described in Table IV. show a very much smaller absorption, so small, in fact, that the quantity of heat produced by the oxidation would appear to be far too little to give rise to any serious increase in temperature. In addition, they seem

TABLE IV.—RATES OF OXIDATION OF SOME SOUTH WALES COALS AT 30° AND 60° CENT.

Sample No. 8, steam-coal from the Big Vein; No. 9, Waterloo red ash (house coal); No. 10, steam-coal from Upper Rhas Las; No. 11, Admiralty steam-coal from the Bute Seam; No. 12, Admiralty steam-coal from the Yard Seam.

| Sample No.. | 9 at 30° Cent. | 8 at 30° Cent. | 10 at 30° Cent. | 11 at 30° Cent. | 12 at 30° Cent. | 8 at 60° Cent. |
|---|---|---|---|---|---|---|
| Rate after hours. | | | | | | |
| 2 | 4·9 | 3·2 | 2·1 | 2·75 | 5·1 | 8·0 |
| 4 | 3·1 | 2·2 | 1·5 | 2·25 | 3·8 | 5·6 |
| 6 | 2·4 | 1·7 | 1·2 | 1·85 | 3·0 | 4·3 |
| 8 | 2·0 | 1·4 | 1·1 | 1·65 | 2·55 | 3·5 |
| 12 | 1·6 | 1·2 | 0·95 | 1·3 | 1·95 | 2·6 |
| 18 | 1·3 | 1·1 | 0·85 | 1·2 | 1·6 | 2·05 |
| 24 | 1·1 | 1·0 | 0·80 | 1·1 | 1·4 | 1·8 |
| 48 | 1·0 | 0·9 | 0·70 | 0·95 | 1·1 | 1·15 |
| 72 | 0·8 | 0·8 | 0·65 | 0·85 | 0·85 | 0·7 |
| 96 | 0·65 | 0·7 | 0·60 | 0·75 | 0·65 | 0·3 |
| Total absorption in 96 hours, in cubic centimetres .. .. | 116 | 100 | 79 | 105 | 134 | 133 |

No sulphate produced during any of the above oxidations.

ANALYSES OF COALS.

| | Sample No. 9. Per cent. | 8. Per cent. | 10. Per cent. | 11. Per cent. | 12. Per cent. |
|---|---|---|---|---|---|
| Moisture .. .. | 1·86 | 1·60 | 1·68 | 1·16 | 0·89 |
| Ash .. .. | 2·03 | 2·88 | 2·54 | 1·55 | 1·55 |
| Carbon .. .. | 83·52 | 85·41 | 85·34 | 88·01 | 88·23 |
| Hydrogen .. .. | 4·94 | 4·52 | 4·53 | 4·01 | 4·09 |
| Nitrogen .. .. | 1·34 | 1·08 | 1·44 | 1·30 | 1·27 |
| Sulphur .. .. | 1·99 | 0·85 | 0·88 | 0·53 | 0·75 |
| Oxygen (by difference) | 4·42* | 3·66 | 3·59 | 3·44 | 3·12 |

* Corrected for sulphur content, 4·79.

to be subject to a limitation in the quantity of oxygen absorbed similar to that already discussed in the case of the anthracites. If sample No. 8 be taken as typical of this set of samples, Table IV. shows that the quantity of oxygen absorbed in 96 hours is larger at 60° Cent. than at 30° Cent., but that at the end of this time the rate of absorption at the higher temperature is half that at the lower—indicating that, although oxygen is being absorbed faster at 60° Cent., the total quantity absorbed will be the same

as at 30° Cent. Such a coal will be quite free from the liability to spontaneous heating. Sample No. 8 would appear to have a capacity for absorbing perhaps 150 cubic centimetres of oxygen, and this would under conditions of perfect heat insulation raise the temperature of the coal 10° Cent. The capacity for further heat production would then be lost, and the coal would cool to the temperature of its surroundings.

TABLE V.—RATE OF OXIDATION OF NORTHUMBERLAND AND DURHAM COALS AT 30° AND 60° CENT.

Sample No. 1, Main Seam; No. 2, waste coal from same place and seam as No. 1; No. 3, Busty Seam; No. 4, Low Main Seam; No. 5, Hutton Seam; No. 6, Low Main Seam (from a different pit from No. 4); No. 7, Yard Coal.

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 5 at 60° Cent. | 7 at 60° Cent. |
|---|---|---|---|---|---|---|---|---|---|
| Rate after hours. | | | | | | | | | |
| 2 | 21·6 | 16·7 | 6·0 | 9·2 | 5·1 | 4·4 | 30·5 | 9·0 | 74·0 |
| 4 | 17·0 | 12·2 | 4·1 | 6·6 | 3·5 | 3·0 | 20·6 | 6·8 | 41·0 |
| 6 | 14·6 | 10·2 | 3·3 | 5·3 | 2·5 | 2·1 | 17·0 | 5·5 | 33·6 |
| 8 | 12·3 | 8·9 | 2·8 | 4·7 | 2·0 | 1·7 | 14·5 | 4·5 | 29·2 |
| 12 | 9·9 | 7·5 | 2·2 | 4·0 | 1·5 | 1·65 | 11·5 | 3·3 | 24·0 |
| 18 | 7·9 | 6·2 | 2·1 | 3·6 | 1·3 | 1·3 | 8·5 | 2·5 | 17·1 |
| 24 | 6·9 | 5·5 | 1·95 | 3·2 | 1·2 | 1·2 | 6·6 | 2·3 | 13·9 |
| 30 | 6·2 | 5·0 | 1·85 | 2·95 | 1·15 | 1·15 | 5·5 | 2·1 | 11·6 |
| 36 | 5·7 | 4·7 | 1·8 | 2·80 | 1·1 | 1·1 | 4·9 | — | 9·9 |
| 48 | 4·8 | 4·4 | 1·6 | 2·60 | 1·0 | 1·0 | 4·2 | 1·9 | 7·9 |
| 60 | 4·1 | 4·0 | 1·4 | 2·30 | 0·9 | 0·9 | 3·6 | — | 6·9 |
| 72 | 3·7 | 3·7 | 1·2 | 2·10 | 0·85 | 0·85 | 3·1 | 1·6 | 6·4 |
| 96 | 3·1 | 3·1 | 1·0 | 1·60 | 0·7 | 0·7 | 2·3 | 1·25 | 5 6 |
| Total absorption in 96 hours, in cubic centimetres .. | 608 | 511 | 176 | 290 | 122 | 118 | 623 | 220 | 1·305 |
| Absorption due to pyrites, in cubic centimetres .. | 81 | 226 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Absorption due to coal, in cubic centimetres | 527 | 285 | 176 | 290 | 122 | 118 | 623 | 220 | 1,305 |

ANALYSES OF COALS.

| Sample No. | 1. Per cent. | 2. Per cent. | 3. Per cent. | 4. Per cent. | 5. Per cent. | 6. Per cent. | 7. Per cent. |
|---|---|---|---|---|---|---|---|
| Moisture .. .. | 9·31 | 6·76 | 2·75 | 5·00 | 1·75 | 1·40 | 11·15 |
| Ash .. .. .. | 3·63 | 36·46 | 7·78 | 4·02 | 1·71 | 2·19 | 1·27 |
| Carbon .. .. .. | 69·16 | 40·19 | 75·47 | 76·94 | 82·29 | 82·66 | 71·70 |
| Hydrogen .. .. | 4·17 | 2·72 | 4·50 | 4·56 | 4·86 | 4·96 | 4·85 |
| Nitrogen .. .. | 1·13 | 0·62 | 1·23 | 1·29 | 1·48 | 1·40 | 1·35 |
| Sulphur .. .. .. | 1·42 | 13·02 | 2·22 | 1·02 | 1·83 | 1·38 | 0·77 |
| Oxygen (by difference) | 11·18 | 0·23 | 6·05 | 7·17 | 6·08 | 6·01 | 8·91 |
| Oxygen corrected for sulphur content | 11·43 | 4·73 | 6·50 | — | 6·39 | 6·15 | — |

Another district in which gob-fires are very rare is in the Northumberland and Durham coalfield. In Table V. the rates of oxidation and the analyses of some samples taken from this field are given.

Of the samples described in Table V., Nos. 3, 5, and 6 have an oxidation much lower than that of the normal oxidizable coal, and the absence of fires is clearly owing to this property. Sample No. 4 has an oxidation rather less than that of sample D27 (Table I.). Only in rare instances does this latter coal give rise to gob-fires, and it would therefore seem that coals having a lower oxidation than this will only originate a heating under the most favourable circumstances. In the Low Main Seam (from which sample No. 4 was taken) the natural conditions are against a gob-fire. Little coal is left in the goaf, and there is a good post roof, which does not readily break up, and so gives every chance of an airtight waste. The coal itself would seem, from other results quoted in this paper, to be just on the limit between a coal liable to fire and one not liable; and, therefore, so long as the conditions are not made exceptionally favourable, no fires will occur.

Sample No. 7 is somewhat different: it shows high oxidation, which increases both in magnitude and in rate with increase of temperature, and it should therefore be liable to fire. In the pit no fires occur, and an inspection of the workings makes the reason of this clear. The seam is about 3 feet thick, with a hard roof and a good floor. The coal is very clean, so that practically none is left behind in the wastes. The absence of fires underground is therefore due to the absence of coal from goaves which might fire. When the coal is taken out of the pit, and stacked on the surface, or loaded as cargo, different conditions obtain, which are more favourable to spontaneous heating, and fires in both cargoes and stacks do occur.

Samples Nos. 1 and 2 were taken from one of the few pits in which gob-fires have broken out in this field. In the normal workings fires are rare, but at exceptional places where the coal thickens, or near a "wash-out" or "overlap," extensive breaks are set up in the roof and the coal. The coal becomes poorer, and is associated with bands of fine pyrites, so that a considerable quantity is thrown back into the goaf. Such places have been the scene of several fires in this pit. Stacks and cargoes of the coal have also been known to fire.

At the place from which samples Nos. 1 and 2 were taken a fire had already occurred. Owing to the nature of the coal, a great deal was being left in the waste, and it was impossible to remove all the timber. The roof was very badly broken, some of the breaks extending through into neighbouring roadways, so that the place had every chance of heating spontaneously, and in fact another fire occurred shortly afterwards. In view of the oxidizable nature of the coal, and the simultaneous oxidation of the pyrites associated with it, samples Nos. 1 and 2 are peculiarly liable to fire. In the second sample nearly half the total oxygen absorbed was taken by pyrites, and since pyrites produces about double the quantity of heat per volume of oxygen absorbed that coal does, nearly two-thirds of the total heat production will come from the admixed pyrites of the sample. The condition of this pyrites seems very similar to that in the Bullhurst Coal, the oxidation of which has already been discussed.* The sample contained little visible pyrites, and no heavy lumps of "brass." The quantity of oxygen absorbed corresponds very nearly with that of the finely-divided Bullhurst sample. From the sulphur content about 24 per cent. of pyrites may be present, which absorbs 226 cubic centimetres of oxygen—that is, 100 grammes would absorb 950 cubic centimetres.

The pyrites evidently may be a very serious factor in causing spontaneous heating in this particular place, if all the waste coal left in the goaf contains as high a proportion of pyrites as sample No. 2. This sample was, however, a picked one, and contained an unusually high percentage; the average of the waste coal would contain perhaps only half as much. It should be noticed, too, that the heat production from sample No. 1, which contains very little pyrites, is nearly equal to that of sample No. 2, which contains a high proportion:—

*Sample No. 1.*

| | | Calories. |
|---|---|---|
| Heat produced by coal ... ... ... | 527 × 2·1 = | 1107 |
| ,, ,, pyrites ... ... ... | 81 × 4·3 = | 348 |
| Total heat production ... ... | = | 1455 |

*Sample No. 2.*

| | | |
|---|---|---|
| Heat produced by coal .. ... ... | 285 × 2·1 = | 598 |
| ,, ,, pyrites ... ... ... | 226 × 4·3 = | 972 |
| Total heat production ... ... | = | 1570 |

* *Trans. Inst. M. E.*, 1916, vol. li., page 504.

Further, the effect of the conditions which obtain in the goaf may modify the relative heat productions a good deal. At a short distance in from the road into a closed waste the oxygen percentage in the air may fall very considerably. If, for example, it were to fall to 10 per cent., the rate of heat production from the pyrites would be just less than half, whilst that from the coal would be a little less than three-quarters of the rate in normal air. The heat production in 96 hours would then be as follows:—

| | Sample No. 1. Calories. | Sample No. 2. Calories. |
|---|---|---|
| From coal ... ... ... ... ... ... | 786 | 425 |
| From pyrites ... ... ... ... ... | 166 | 463 |
| Totals ... ... ... ... ... | 952 | 888 |

The heat produced by the pyrites in sample No. 2 is, therefore, little more than that produced by the coal in the sample, and much less than that from the coal in sample No. 1. Very possibly, therefore, in the goaf samples Nos. 1 and 2 would be about equally liable to fire, and it would be difficult to say which was the responsible agent, the coal or the pyrites. In one place where the percentage of pyrites was very low (sample No. 1), undoubtedly the origin of the heating would be in the coal. In another place where the percentage of pyrites was rather higher than that in sample No. 2 (24 per cent.), the larger proportion of the heat would come from the pyrites, but the two places would be almost equally liable to fire.

A very different proportion between the heat production by coal and by pyrites is found in the Bullhurst Seam in North Staffordshire. The oxidation of the pyrites associated with this coal has already been discussed.* The oxidations of the coals are recorded in Table VI.

It is quite clear that the coals from this particular section of the Bullhurst Seam cannot be responsible for the fires which occur, even if the percentages of pyrites normally associated with them (to the extent shown by the oxidations and analyses in Table VI.) be taken into account. In some places, however, there is a very high percentage of pyrites in a very finely-divided condition mixed with the coal, and it must be at these points that the initial rise in temperature required to cause the coal to fire is produced.

* *Trans. Inst. M. E.*, 1916, vol. li., page 504.

At low temperatures the rates of oxidation of the samples described in Table VI. are very similar to those of the South Wales coals described in Table IV.; but, as the temperature rises, the quantity of oxygen that the coal is capable of absorbing also seems to increase, which was not the case with the Welsh coals. The rate of increase is very small, but it seems to be real. When the pyrites has produced a sufficiently large rise in temperature, the coal will begin to produce a more considerable quantity of heat by its own oxidation. There is no doubt at all that the initial rise in temperature is due to the oxidation of the pyrites, and that in its absence the coal could not produce sufficient heat at ordinary temperatures to cause any noticeable increase in temperature. Details of the outbreak of fire in the Bullhurst Seam confirm the conclusion that pyrites must be the origin. It is said that heaps of coal and "dirt" left at the face have fired in from 24 to 48 hours. No coal yet examined is capable of generating heat spontaneously at this rate, but if the heap contained in one part a very high percentage of pyrites in that state in which it is found in the Bullhurst Seam, then it has been shown* that a fire may easily break out in this time.

The analyses recorded in Table VI. are interesting, since they show that not all the sulphur can be present as pyrites. Every part of sulphur in the form of pyrites leaves 1·25 parts of ferric-oxide ash when the coal is burnt, so that, calculating from the sulphur content and allowing no ash to the coal, the weights of ash in samples Nos. 15, 17, 18, and 19 would be 4·37, 3·14, 3·70, and 4·81 per cent. respectively. In each case, except the last, the ferric oxide would weigh more than the actual weight of ash from the sample. Obviously, therefore, part of the sulphur must be present as organic compounds, and since the coal itself will give some ash, a fair allowance for the organic sulphur seems to be about 1 per cent.

Although pyrites is the main cause of heating in the Bullhurst Seam in North Staffordshire, it has little to do with spontaneous combustion in the Thick Coal in South Staffordshire. The rates of oxidation of some samples from the thick coal are recorded in Table VII.

The pit from which these coals are taken is very liable to fire, as might be expected from the oxidizable nature of the coals.

* *Trans. Inst. M. E.*, 1916, vol. li., page 509.

The seam is often divided by thin vertical partings, which seem to contain a high proportion of pyrites, and along which breaks often develop. A sample of this pyritic material has been

TABLE VI.—RATES OF OXIDATION OF VARIOUS PARTS OF THE BULLHURST SEAM, NORTH STAFFORDSHIRE.

Sample No. 15, Bottoms or Wall coal; No. 16, Hard part of Bottoms; No. 17, Middles; No. 18, Hustle; No. 19, Little Tops; No. 20, Big Tops.

| Sample No. | 15 | 16 | 17 | 18 | 19 | 20 | 16 at 60° Cent. | 17 at 60° Cent. | 19 at 60° Cent. |
|---|---|---|---|---|---|---|---|---|---|
| Rate after hours. | | | | | | | | | |
| 2 | 5·4 | 3·0 | 5·4 | 4·2 | 3·1 | 2·8 | 8·3 | 9·7 | 8·0 |
| 4 | 3·7 | 2·6 | 3·7 | 2·6 | 2·0 | 1·9 | 6·2 | 7·2 | 4·9 |
| 6 | 2·85 | 2·3 | 2·85 | 1·9 | 1·55 | 1·3 | 5·8 | 5·9 | 3·4 |
| 8 | 2·50 | 2·05 | 2·5 | 1·6 | 1·35 | 1·1 | 5·2 | 5·1 | 2·6 |
| 12 | 2·1 | 1·75 | 2·1 | 1·45 | 1·20 | 0·9 | 4·4 | 4·4 | 2·05 |
| 18 | 1·85 | 1·6 | 1·85 | 1·40 | 1·15 | 0·85 | 3·6 | 3·9 | 1·9 |
| 24 | 1·65 | 1·45 | 1·65 | 1·35 | 1·1 | 0·8 | 3·25 | 3·45 | 1·8 |
| 30 | 1·50 | 1·3 | 1·5 | 1·30 | 1·05 | 0·75 | 3·0 | 3·1 | 1·65 |
| 48 | 1·30 | 1·1 | 1·3 | 1·25 | 1·0 | 0·70 | 2·25 | 2 4 | 1·4 |
| 72 | 1·20 | 1·0 | 1·2 | 1·1 | 0·9 | 0·6 | 1·85 | 2·0 | 1·05 |
| 96 | 1·10 | 0·9 | 1·1 | 0·95 | 0·75 | 0·5 | 1·5 | 1·7 | 0·7 |
| Total oxygen absorbed in 96 hours, in cubic centimetres .. | 167 | 132 | 167 | 133 | 107 | 81 | 273 | 292 | 164 |
| Total oxygen absorbed by pyrites, in cubic centimetres .. | 35 | 35 | 20 | not | deter mined. | | 130 | 70 | 30 |
| Total oxygen absorbed by coal, in cubic centimetres .. | 132 | 97 | 147 | — | — | — | 143 | 222 | 134 |

ANALYSES OF COALS.

| Sample No. | 15. Per cent. | 16. Per cent. | 17. Per cent. | 18. Per cent. | 19. Per cent. | 20. Per cent. |
|---|---|---|---|---|---|---|
| Moisture .. .. | 2·12 | 3·50 | 2·25 | 2·37 | 1·80 | 1·94 |
| Ash .. .. .. | 3·60 | 39·82 | 2·73 | 2·39 | 2·68 | 4·86 |
| Carbon .. .. .. | 77·93 | 44·29 | 79·31 | 78·87 | 78·56 | 76·80 |
| Hydrogen .. .. | 5·35 | 3·42 | 5·48 | 5·20 | 5·35 | 4·85 |
| Nitrogen .. .. | 0·80 | 0·86 | 0·69 | 0·60 | 0·92 | 1·21 |
| Sulphur .. .. | 3·50 | 3·11 | 2·27 | 2·51 | 2·96 | 3·85 |
| Oxygen (by difference) | 6·70 | 5·00 | 7·27 | 8·06 | 7·73 | 6·49 |
| Oxygen corrected for sulphur content .. | 7·63 | 5·80 | 7·75 | 8·63 | 8·46 | 7·55 |

examined. It consists of a soft bright yellow mass, apparently composed of flaky crystals, and showed very little oxidation *in situ*. The measured rate of absorption of oxygen is set forth

in Table VII. Sample No. 42 contained about 54 per cent. of pyrites, which absorbed 131 cubic centimetres of oxygen in 96 hours; at the same rate 100 grammes of pure pyrites would have absorbed 250 cubic centimetres, or only about a quarter of the quantity absorbed by other specimens of pure finely-ground pyrites. This must indicate that sample No. 42 contains the pyrites in very small crystals, which are about small enough to pass a 60-mesh sieve, and that the surfaces of these crystals, like those of the larger ones, are not readily attacked by oxygen.

TABLE VII.—RATES OF OXIDATION OF SAMPLES OF THICK COAL AT 30° CENT.

Sample No. 38, White coal; No. 39, Rooves coal; No. 40, Top stone coal; No. 41, Bottom stone coal; No. 42, Pyritic material from partings in coal; No. 42*a*, same sample as No. 42, but passes a 10-mesh and is left on a 30-mesh sieve.

| Sample No. | 38 | 39 | 40 | 41 | 42 | 42a |
|---|---|---|---|---|---|---|
| Rate after hours. | | | | | | |
| 2 | 22·0 | 25·2 | 19·0 | 15·6 | 13·7 | 3·4 |
| 4 | 16·2 | 17·6 | 15·0 | 11·0 | 9·8 | 2·9 |
| 6 | 13·5 | 14·0 | 11·6 | 8·4 | 7·8 | 2·5 |
| 8 | 11·3 | 11·9 | 9·6 | 7·0 | 6·7 | 2·2 |
| 12 | 8·5 | 8·7 | 7·2 | 5·6 | 5·4 | 1·7 |
| 18 | 6·5 | 6·5 | 6·3 | 4·55 | 4·4 | 1·2 |
| 24 | 5·6 | 5·6 | 5·6 | 4·0 | 4·0 | 1·1 |
| 30 | 5·0 | 5·0 | 5·1 | 3·6 | 3·7 | 1·0 |
| 36 | 4·4 | 4·4 | 4·6 | 3·2 | 3·4 | — |
| 48 | 3·6 | 3·6 | 3·8 | 2·6 | 2·9 | 0·9 |
| 60 | — | — | — | — | — | — |
| 72 | 2·6 | 2·6 | 2·8 | 1·8 | 2·7 | — |
| 96 | 2·1 | 2·1 | 2·3 | 1·1 | 1·7 | 0·65 |
| Total oxygen absorbed in 96 hours, in cubic centimetres | 512 | 532 | 489 | 344 | 356 | 110 |
| Oxygen absorbed by pyrites, in cubic centimetres | — | — | 90 | 50 | 131 | not determined |
| Oxygen absorbed by coal, in cubic centimetres | 512 | 532 | 399 | 294 | 225 | — |

ANALYSES OF COALS.

| Sample No. | 38. Per cent. | 39. Per cent. | 40. Per cent. | 41. Per cent. |
|---|---|---|---|---|
| Moisture | 15·05 | 15·51 | 14·09 | 11·38 |
| Ash | 3·64 | 3·61 | 7·44 | 12·78 |
| Carbon | 64·63 | 64·73 | 61·62 | 57·51 |
| Hydrogen | 4·27 | 4·30 | 4·10 | 4·11 |
| Nitrogen | 0·96 | 0·97 | 0·75 | 0·98 |
| Sulphur | 1·01 | 1·01 | 3·29 | 2·53 |
| Oxygen (by difference) | 10·44 | 9·87 | 8·71 | 10·71 |
| Oxygen corrected for sulphur content | — | — | 9·57 | 11·28 |

| Sample No. 42. | Per cent. |
|---|---|
| Moisture | 6·3 |
| Ash (other than ferric oxide) | 5·6 |
| Coal (ash free, dry) | 34·0 |
| Pyrites | 54·1 |
| | — |
| | — |
| | — |

In a break formed along one of these veins of pyrites a great deal of the heat production may come from the pyrites. Supposing that the dust in the break had the composition of sample No. 42, it would account for rather more than half the heat produced:—

| | Calories. |
|---|---|
| Heat produced by coal = 225 × 2·1 ... ... ... | = 472 |
| ,, ,, pyrites = 131 × 4·3 ... ... | = 563 |
| Total ... ... ... ... ... ... ... | 1,035 |

But even with this high percentage of pyrites, more heat would be produced if the break were filled with coal-dust.

The average from samples Nos. 38, 39, and 40 = 510 × 2·1 = 1,071 calories—especially when the reduction of the oxygen percentage in the break is considered, as in the case of sample No. 2 (Table V.). Whilst, therefore, the origination of some heatings in this mine may be assisted by pyrites, the bulk of the coal would appear to fire equally readily in its absence.

TABLE VIII.—RATE OF OXIDATION OF LIGNITE.
Sample obtained from Portrush.

| Sample No. | 37 at 30° Cent. | 37 at 60° Cent. |
|---|---|---|
| Rate after hours. | | |
| 2 | 88·0 | — |
| 4 | 60·0 | 200 |
| 6 | 44·5 | 125 |
| 8 | 34·5 | 85 |
| 12 | 23·5 | 60 |
| 18 | 18·0 | 42 |
| 24 | 15·0 | 34·5 |
| 30 | 12·9 | 30 |
| 36 | 11·3 | 28 |
| 48 | 9·2 | 23·5 |
| 60 | 7·6 | 19·2 |
| 72 | 6·5 | 16·1 |
| 96 | 5·2 | 12·1 |
| Total oxygen absorbed in 96 hours, in cubic centimetres .. | 1,476 | 3,800 |

ANALYSIS OF SAMPLE No. 37.

| | Per cent. |
|---|---|
| Moisture .. .. .. .. .. .. .. | 24·87 |
| Ash .. .. .. .. .. .. .. | 18·31 |
| Carbon .. .. .. .. .. .. .. | 36·52 |
| Hydrogen .. .. .. .. .. .. .. | 3·48 |
| Nitrogen .. .. .. .. .. .. .. | 0·41 |
| Sulphur .. .. .. .. .. .. .. | 1·00 |
| Oxygen (by difference) .. .. .. .. .. | 15·41 |

The lignite described in Table VIII. is about three times as oxidizable as any other coal examined, but in the particular mine from which the sample was taken it does not fire spontaneously. As the pit is very wet, often being flooded, and the roadways are normally knee-deep in water, this is not remarkable. In drier lignite mines, especially in Germany, fires occur very readily, as would be expected. The very high proportion of water naturally contained by lignite reduces the liability to spontaneous combustion, otherwise it would be difficult to see how the coal could be worked at all. For lignite containing 25 per cent. of moisture to reach 100° Cent. and evaporate off its water requires an expenditure of about 17,000 calories of heat, which would correspond to an oxygen-absorption of about 8·5 litres per 100 grammes. This large expenditure of energy brings the possible spontaneous rate of increase in temperature down to that of a normal oxidizable coal.

TABLE IX.—RATES OF OXIDATION OF AYRSHIRE COALS AT 30° AND 60° CENT.

Sample No. 33, Bottom coal; No. 34, Middle coal or No 2 Seam; No. 35, Top coal or No. 3 Seam; No. 36, "Smithy" coal.

| Sample No. | 33 | 34 | 35 | 36 | 34 at 60° Cent. |
|---|---|---|---|---|---|
| Rate after hours. | | | | | |
| 2 | 36·0 | | 17·5 | 5·5 | 52 |
| 4 | 15·4 | | 11·9 | 4·0 | 32 |
| 6 | 11·9 | | 8·9 | 3·2 | 25·4 |
| 8 | 10·0 | | 6·9 | 2·7 | 21·2 |
| 12 | 7·4 | | 5·0 | 2·15 | 16·6 |
| 18 | 6·8 | | 4·3 | 1·7 | 12·8 |
| 24 | 5·0 | | 3·9 | 1·35 | 11·0 |
| 30 | 4·4 | | 3·7 | 1·1 | 10·0 |
| 36 | 4·0 | | 3·4 | 1·0 | 9·2 |
| 48 | 3·4 | | 3·0 | 0·85 | 8·0 |
| 60 | 2·9 | | 2·7 | — | 7·2 |
| 72 | 2·4 | | 2·45 | 0·7 | 6·5 |
| 96 | 1·9 | | 2·05 | 0·6 | 5·8 |
| Total oxygen absorbed in 96 hours, in cubic centimetres | 502 | | 392 | 124 | 1,100 |

ANALYSES OF COAL.

| Sample No. | 33. Per cent. | 34. Per cent. | 35. Per cent. | 36. Per cent. |
|---|---|---|---|---|
| Moisture .. .. .. .. | 8·05 | 6·94 | 5·74 | 9·72 |
| Ash .. .. .. .. .. | 4·62 | 4·81 | 8·03 | 3·47 |
| Carbon.. .. .. .. .. | 72·44 | 73·05 | 71·06 | 70·44 |
| Hydrogen .. .. .. .. | 4·59 | 4·69 | 4·53 | 4·69 |
| Nitrogen .. .. .. .. | 0·98 | 0·80 | 1·02 | 1·23 |
| Sulphur .. .. .. .. | 0·76 | 0·69 | 0·77 | 0·73 |
| Oxygen (by difference) .. .. | 8·56 | 9·02 | 8·85 | 9·72 |

Lignite produces far more carbon dioxide per volume of oxygen absorbed than any other coal. After 120 hours at 30° Cent., about a quarter of the volume of oxygen absorbed reappears as carbon dioxide, and at 60° Cent. about half; this is between four and five times as much as is produced by a true coal.

In Table IX. the rates of oxidation of some samples of Ayrshire coals are recorded. The mine from which these samples were taken had had two fires, and the heated areas were sealed off. It was not known which coal caused the fires, but the "Smithy" coal was suspected. The three main seams all have a rate of oxidation which would render them liable to fire, whilst that of the "Smithy" coal shows that it cannot be the cause of a spontaneous heating. No evidence of any oxidation of pyrites was found.

Of the forty coals examined, twenty-two are from pits in which fires have occurred, twelve from pits in which fires are not known, and six from pits in which fires do occur, but are not attributable to the coal. The time-absorption curves of all the coals are of the same type, but vary considerably in magnitude. A convenient way of classifying the oxidation of the samples is by the quantity of oxygen absorbed during the first 96 hours. Three main divisions are then apparent, namely:—

(1) Those like anthracite and the Welsh steam-coals, which have a small definite capacity for oxygen, which is not altered by increase of temperature (at any rate, up to 60° Cent.), and cannot therefore fire spontaneously.

(2) Those which have a low rate of oxidation, the capacity for which does increase with temperature, but are not liable to spontaneous combustion unless mixed with pyrites (see Table V., samples Nos. 3, 5, and 6, and Table VI.).

(3) Those coals which have a sufficiently large rate of oxidation to give rise to fires without the intervention of any other substance (see Tables I. and II.).

There does not seem to be a gradual transition between classes 2 and 3 in the quantity of oxygen absorbed. Those coals that are not liable to fire usually absorb less than 200 cubic centimetres of oxygen in 96 hours at 30° Cent., and those liable to fire well over 300 cubic centimetres in the same time. The measurement of the oxidation of a coal by the methods described should therefore

be a ready means of distinguishing between these classes, especially if measurements are made both at 30° and at 60° Cent. If a sample shows a very low oxidation, it cannot be said definitely that it is not liable to fire unless the quantity and kind of pyrites found in the seam is also known (see the samples in Table VI.). So long as the pyrites is all in the form of "brass," or as bright thin veins, it plays no part in causing a heating. If, however, it is found in high proportion as an intimate mixture with the coal, it may become the deciding factor, causing a coal which is not of itself liable to fire to become liable.

The ultimate analysis of a coal seems to give little definite information as to its liability to spontaneous heating. A coal which contains both a high percentage of moisture and a high percentage of oxygen is usually more oxidizable than one with low oxygen and low moisture. The oxygen percentage by itself is no guide to the capacity of the coal for absorbing oxygen. For example, sample No. 7 contains 8·93 per cent. of oxygen and absorbs 623 cubic centimetres; whilst sample No. 18 contains almost the same percentage of oxygen within the limits of experimental error and only absorbs 133 cubic centimetres. The latter sample contains more oxygen than sample No. 25, of which the absorption is 3½ times as great. A number of other instances of the same sort can be found in the tables given in this paper. A high natural moisture content is on the whole a more reliable indication, but no one constituent in the coal can be said to vary regularly with the oxygen-absorption. The quantities of oxygen and moisture already in the coal do not themselves influence the absorption of oxygen, but are indications of the presence of other compounds or classes of compounds in the coal-substance which are easily oxidized. If water had any direct influence on the absorption, then addition of water to coals of low moisture content should increase their power of absorption. In every sample of which the oxidation has been measured the natural moisture present was enough for the coal to exert its full capacity. Complete removal of the last traces of water does reduce the rate of absorption considerably,* but the re-addition of 1 per cent. of moisture is amply sufficient in most cases for the coal to regain its activity.

* See *Trans. Inst. M. E.*, 1915, vol. xlix., page 39.

A suggestion has been made* that it is the oxygen normally present in coal which causes spontaneous heating, the theory being that the coal may be considered to consist of two parts, one containing much oxygen and the other little oxygen. The part containing little oxygen is supposed to react with the other part and abstract some of its oxygen, the reaction being accompanied by evolution of heat. No experimental evidence in favour of this view has been adduced. There is, however, definite evidence against it, so far as it refers to the origin of gob-fires. During a study of the thermal changes which take place when coal is heated *in vacuo*, Cobb has shown that no distinct exothermic change takes place until the temperature reaches 600° Cent.†—that is to say, until the coal is red hot. Before this point such thermal changes as do occur are mainly accompanied by an absorption of heat. It is difficult to see how a change which does not take place until the coal is red hot can be the cause of its arriving at a red heat.

On the other hand, there is abundant evidence to support the commonly-accepted view that spontaneous heating is due to the heat evolved during the absorption of oxygen from the air by coal or pyrites. The quantity of heat produced by the reaction has been measured, and it has been shown that the observed rate of heating of a sample of coal agrees with the rate calculated from the heat of reaction and the rate of absorption of oxygen.

In conclusion, the writer tenders his best thanks to Dr. J. S. Haldane for his assistance in the selection and collection of the samples, and for his constant advice during the carrying out of the analyses and measurements. He and the writer wish also to acknowledge most gratefully the invaluable help given by Dr. W. N. Atkinson, Mr. A. D. Nicholson, and Mr. J. R. R. Wilson, H.M. Inspectors of Mines; by Prof. John Cadman; by Mr. Granville Poole; and by the managements of the various collieries from which samples were obtained.

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* R. V. Wheeler, *Minutes of Evidence, Departmental Committee on Spontaneous Combustion in Coal Mines*, April 18th, 1913.

† "Thermal Phenomena in Carbonization," by Harold Hollings and John W. Cobb, *Journal of Gas-lighting*, 1914, vol. cxxvi., page 917.

Mr. C. C. ELLISON (Monckton Main Colliery) said that the point in the paper that was of most interest to him was the abnormal sample containing so slight a percentage of pyrites, but which would start a fire in a very short time in a way that nobody ever expected that a fire could originate. He had himself experienced within the last 18 months a fire in a stack of coal that contained practically no gas, and which nobody would have expected to fire. The heap was about 20 feet thick, and he had often wondered why this coal had fired; but he now thought that probably it was an abnormal sample that caused the fire. Those who had never had experience of a gob-fire were very much in the position of those who had not been out of England during the present awful war; it was really impossible to realize the difficulties with which some had to contend owing to this fearful danger. He sincerely hoped that the younger members would take up this matter, and that in their scientific training it would be brought home to them in the laboratories which now existed, of which the older members did not have the advantage.

Prof. HENRY LOUIS (Armstrong College, Newcastle-upon-Tyne) said that any light which could be thrown on a subject like this was important, and that was why he would venture to contribute a criticism on one particular point in the paper, dealing particularly with the pyrites question. He was inclined to think that the paper might be vitiated by the omission to take into account the fact that there were two entirely different kinds of pyrites. It was well known that the mineral bisulphide of iron occurred both in the ordinary cubical form of pyrites and in the rhombic form, commonly known as marcasite, which was slightly different both in colour and in its crystalline structure. Anyone who had interested himself in mineralogy knew that under ordinary atmospheric conditions marcasite or rhombic pyrites decomposed very rapidly, whilst the cubical pyrites remained unaltered for, at any rate, an ordinary man's lifetime, and probably a great deal longer. Mr. Winmill throughout had dealt with pyrites as of one and the same nature, and had talked of the oxidation of pyrites without distinguishing between the two varieties. Possibly the author had thus fallen into an error which was very much of the same order as making experiments on the rate of combustion of a diamond, and then applying the figures to the combustion of graphite, this being an exact parallel

between the two cases. He held from his observation—and it was a point of view which was also confirmed by some mineralogists—that pyrites occurred in coal in the form of marcasite as well as of cubical pyrites, and unless that point was definitely borne in mind, and unless it was determined in every case which of the two was being dealt with, difficulties would arise, because it made much difference whether the pyrites was readily oxidizable or not. Marcasite was readily oxidizable, and set up heating very rapidly. He would not be surprised to find that the calorific power of these two forms of pyrites was different, and that it might be possible for marcasite to give out more heat than the cubical variety. This was merely a suggestion; but unless an investigator indicated in each case which kind of pyrites he was dealing with, he would not be giving all the data, and it was on that account that he (the speaker) ventured to draw special attention to the point.

Another matter about which he was not very clear was how the amount of pyrites in the coal was determined. So far as he could gather from an allusion in one of the papers, the percentage of sulphur was determined, and the amount of pyrites—if he might say so—was guessed at from that. Some years ago he had made an investigation into the occurrence of sulphur in coal, and this had led him to definite conclusions. The sulphur in coal was combined partly with iron and was partly in the form of an organic compound, and he had come across cases where the amount of sulphur in such organic compounds was very great indeed. It might interest Mr. Winmill to know that the only method that he himself thought at all reliable for working out the subject was to grind the coal very finely and float it in a strong solution of zinc iodide, which allowed the pyrites to settle so that the percentage could be determined. That was the only way to get at the quantity of pyrites present. It was, of course, very likely that a great deal had yet to be worked out in this connexion, and he hoped that it would be perfectly understood that he was speaking by no means in disparagement of the invaluable work done by Mr. Winmill and the Doncaster Committee. He was merely trying to contribute a little to the elucidation of an exceedingly important and complicated subject.

Mr. W. McD. Mackey (Leeds) said that the papers on the absorption of oxygen by coal would become classic. The work

had been done very thoroughly, and when it was finished the industry would certainly be in possession of data bearing on the oxidation of coal that would be exceedingly valuable in the future.

With reference to the question of pyrites, Prof. Louis's query was perhaps almost answered in the paper itself, because he understood that Mr. Winmill had pointed out what Prof. Louis had mentioned, namely, that it was the physical condition of the pyrites that was important—that the fine pyrites undoubtedly was the dangerous kind, and that the cubical form was not so dangerous.

Prof. Louis thought that the question went a great deal deeper than this, and that it was a matter of molecular rather than physical condition.

Mr. Mackey, continuing, said that the question of moisture in coal, as Mr. Winmill had pointed out in his paper on "The Absorption of Oxygen by Coal," was valuable apart from the question of the amount of water that was in the coal. As Mr. Winmill had stated, a coal that contained a large percentage of moisture was more apt to take up oxygen than a coal that contained a smaller percentage. He only mentioned this to show that the question of water or moisture in coal was of importance apart from the question of the commercial value of coal containing less or more moisture. Any chemist who had carried out analyses of coal would be struck with the point that coal-seams of the newer formations contained persistently 8 or 9 per cent. of water, whereas older seams contained only 2 or 3 per cent., and he confessed that for a long time he was under the impression —although he had not formulated any theory as to it, even in his own mind—that the water in the coal was in some way loosely combined with the coal, and that it entered into its chemical composition. That idea, however, was altogether erroneous, for it was well known that water was contained in the coal simply as water—that is, the water could be got out at ordinary temperature by keeping it in a vacuum over a desiccating agent like sulphuric acid; and from some experiments that he had carried out recently to ascertain the extent to which coal would take up water, he had found that an anthracite which showed 2·22 per cent. of water when it was dried *in vacuo*, took up 2·25 per cent. when it

was allowed to stand in a moist atmosphere. Another coal that showed 7·78 per cent. of moisture when dried *in vacuo* absorbed 7·77 per cent. when allowed to stand in a moist atmosphere. In other words, these coals took up exactly the same amount of water that they had given out. The only coal in which he had found an anomaly was an Italian lignite, which showed 15·59 per cent. of moisture when dried *in vacuo*, but absorbed 20·47 per cent. when allowed to stand in a moist atmosphere; but the general result of his experiments was that coal took up about the same amount of moisture that it gave out. The fact was not novel: it was known before, and he only mentioned it because he happened to have done the work, and it was brought forcibly home to him. The question that Mr. Winmill raised of the accurate determination of moisture or water was therefore very valuable, and would lead to results showing what the nature of the coal itself was. It was evidently the texture or the physical condition of the coal which allowed it to hold the moisture, and that gave an insight perhaps into other matters connected with coal. He had had an opportunity of seeing Mr. Winmill's method of determining moisture as described in the paper, but though, at first sight, he liked the method, yet he had come back to the opinion that the old-fashioned method of determining the moisture of the sample by heating at 105° Cent. was at least as good as the one adopted by Mr. Winmill. Mr. Winmill had given several results, all of which went to show that the method of heating the coal *in vacuo* gave higher figures than any other process. With regard to the five factors into which Mr. Winmill had divided the subject, the first was the loss in weight due to the loss of moisture, and the second the loss in weight due to the expulsion of the gas from the coal (although Mr. Winmill later on stated that this was of no value, and might therefore be left out of account as of no great moment). The third factor was the gain in weight due to the absorption of oxygen by the coal. That was Mr. Winmill's special domain, namely, the absorption of oxygen by coal, and the question was whether or not it was a serious factor under the conditions of drying at 105° Cent. Mr. Winmill said that it was. The fourth factor was the loss in weight due to the formation of water and carbon dioxide by the interaction of the carbon, hydrogen, and the oxygen of the coal; but any water formed by the interaction of the

hydrogen and oxygen of the coal at 105°—110° Cent. would be found in Mr. Winmill's calcium-chloride tube, and he (the speaker) thought that this, in part at least, might account for the high results that Mr. Winmill had found. The fifth factor was gain in weight due to the reabsorption of moisture by the coal from the air during weighing. There he joined issue with Mr. Winmill at once, because he was quite sure that he attached far too much importance to this point. It was quite well known that any dry substance took up water very rapidly and that any wet substance gave it off, but in the laboratory Mr. Winmill knew as well as he did that when they dealt with organic substances like these, if they wished to be absolutely correct this factor must be provided for, and it was the ordinary work of any laboratory to provide against mistakes of that kind. In his own laboratory he usually took 10 grammes on an open watch-glass, a method which Mr. Winmill would, of course, say was altogether wrong. That might be so, but in a commercial laboratory, when there were a dozen samples of coal to be dealt with, they could not afford to be too particular about the exact procedure. The analyses had to be done quickly, but at the same time correctly, and although a boy or a young assistant might not be troubled over much with his conscience, yet he really wanted to get through with the work, and his results would probably be more accurate than those of the chemist who tried to be absolutely correct. He knew approximately the weight, and before taking the watch-glass out of the desiccator he put the weights on the balance, so that he was only a few moments in finding the correct weight. It must be remembered that the balance case itself was of the nature of a desiccator. For purposes of comparison, he (the speaker) had done some work recently, using what he considered to be the standard method of drying, namely, at the ordinary temperature over sulphuric acid in a vacuum desiccator. This eliminated any error due to factors 3 and 4, and the error due to factor 2 they both agreed was unimportant. Taking four coals, in one case he found 2·22 per cent., whereas in the usual method, that is, weighing after heating at 105° Cent., he found 2·34 per cent. Then came the Italian lignite which by the vacuum method gave 15·59 and by the usual method 15·61 per cent. Another coal gave 1·1 by the vacuum method and 1·12 per cent. by the usual method, whilst another gave 7·78 and 7·70

per cent. respectively. These were all in practical agreement, and, he considered, proved that the ordinary method when properly carried out by heating at 105° Cent. was, at any rate, as correct as Mr. Winmill's method.

Mr. WILLIAM SMITH (Dalmellington) said, with reference to Table IX. in the paper on the absorption of oxygen by coal, that the coals mentioned had been giving trouble for 40 years. It had always been considered that the "Smithy" Coal was the defaulter, yet it was surprising that, according to Mr. Winmill, this was not the coal that gave trouble. The section of the seam was interesting, the working of which has been described in the *Transactions*.* Commencing at the bottom, the section was as follows:—

| | Feet. | | Feet. | Inches. |
|---|---|---|---|---|
| Coal ... ... ... ... ... ... ... | 4 | to | 5 | 9 |
| Stone ... ... ... ... ... ... ... | 4 | | | |
| Coal ... ... ... ... ... ... ... | 4 | ,, | 5 | 0 |
| Stone ... .. ... ... ... ... ... | 0 | ,, | 4 | 0 |
| Coal ... ... ... ... .. ... ... | 6 | ,, | 7 | 0 |
| Fireclay ... ... ... ... ... ... ... | 2 | | | |
| Coal (Smithy) ... ... ... ... ... ... | 3 | ,, | 4 | 0 |

The section often measured 22 feet of coal altogether. The bottom and middle seams were worked on the ordinary longwall advancing system, and the top 6 feet of coal by longwall retreating, the Smithy Coal (an unworkable portion) being allowed to fall in the goaf. Fires had occurred in the goaf, but not in any of the other seams; and it came very much as a surprise, therefore, to find that the Smithy Coal was not guilty. The three seams that were worked were sometimes laid down in stacks on the surface 18 feet high, containing 7,000 to 10,000 tons, just as they came out of the pit, and there had never been any trouble with spontaneous heating on the surface. He would like to know whether the oxidation in those seams reached a limit, so that when laid down on the surface no oxidation took place.

Dr. J. S. HALDANE (Oxford) asked whether the coal was coarse. His recollection of the stacks was that they consisted of rather coarse coal, mostly in big lumps.

Mr. SMITH said that the stacks when refilled contained about 50 per cent. of small coal that had passed over a $1\frac{5}{8}$-inch screen.

* *Trans. Inst. M. E.*, 1904, vol. xxviii., page 2.

Mr. D. M. MOWAT (Coatbridge), referring to the variation in moisture in certain seams, said that in Scotland this was quite distinguishable between the Coal-Measures proper and the Carboniferous Limestone. In the Coal-Measure seams there was from 9 to 11 per cent. of moisture, whilst in the Carboniferous Limestone seams the amount was about 4 or 5 per cent. Had Mr. Winmill any suggestion to make as to the reason for that difference? He (Mr. Mowat) did not remember ever having heard any reason put forward. Referring to the question of the ascertainment of moisture in coal, what was wanted was the percentage of moisture inherent in the coal. Seeing that coal reabsorbed the moisture which was driven off on drying at 100° Cent., the proper way to ascertain the moisture would perhaps be to leave it for two or three days, because to take a sample which was splashing wet would not yield accurate results, as it would contain externally acquired moisture as well as that inherent in the coal. He had noticed differences in samples brought in wet as compared with samples that had lain for a day or two, and it was this latter policy which seemed to be the best, for the coal would not lose its inherent moisture, seeing that it acquired it again if left alone. He would like to draw Mr. Winmill's attention to a place where there was a great deal of pyrites in an ironstone mine which had been under water for 20 years. The water coming from the mine was slightly alkaline, but when the pyrites was exposed to air and moisture, the result was a solution that was strongly acid. He did not know whether that was a peculiar state of affairs, or was normal.

Mr. G. L. KERR (Glasgow) said that, with regard to the amount of moisture in coal, he had two seams in view which were well known to him, and his experience of these did not agree with what had been said regarding the moisture in coal-seams proper and those in the Carboniferous Limestone. He had noticed that coals of inferior quality usually carried a high percentage of water, and this fact was borne out by one seam at Campbeltown and another in North Ayrshire, both of which were at the very bottom of the Carboniferous Limestone formation, and contained very high percentages of water. It was interesting that these low-grade coals usually carried a high percentage of moisture, and one of the examples quoted by Mr. Mackey, namely, the Italian lignite, confirmed this, lignite, of

course, being an inferior quality of coal. Some explanation of this fact would be useful. With regard to pyrites, the Lanarkshire Ell Coal came practically first, that is, 6 to 8 feet of Ell Coal and 2 feet of head coal, which was left in the workings. The Ell Coal did not so easily take fire, but now that the old workings were being opened up an endeavour was made to recover the 2 feet of head coal. This coal was continuously the cause of fire when it was exposed to the atmosphere, although it did not fire in the seam. That might or might not be due to the amount of iron pyrites contained in the head coal, but the fact remained that the head coal contained a fairly high percentage of iron pyrites.

Dr. J. S. HALDANE said that he had really nothing to add to what was contained in the papers. What was aimed at at the Doncaster coal-owners' laboratory was to obtain definite measurements of everything, and that Mr. Winmill had been able to do with extraordinary success. First of all, he had tried to obtain a definite measurement of the heat produced when a given amount of oxygen was absorbed, and that, he thought, had been accomplished successfully. It was now known that the absorption of oxygen, which was much more easy to measure, was a definite measurement of the heat production, and it was the heat production that was practically the important factor in connexion with gob-fires and underground temperatures. There was now a solid basis on which to go with regard to the pyrites theory. He and Mr. Meachem, in a paper written in 1898, had embraced the pyrites theory and had resuscitated it. It seemed to him then that pyrites was probably responsible for gob-fires, for there was only a little of it in the coal, and whatever it was in the coal that was responsible for the heating was very quickly exhausted. That something seemed rather to correspond to pyrites, and in the Staffordshire coal there was abundant direct evidence of the oxidation of pyrites. The oxidation of pyrites would account for the disappearance of oxygen; and they could also account for the appearance of carbon dioxide, on the assumption that carbonates were decomposed by the sulphuric acid formed by the oxidation of pyrites, so that matters seem to work out fairly well on the whole for the pyrites theory. When, however, the Barnsley Seam was attacked by Mr. Winmill, the pyrites theory was blown to atoms. There was no oxidation of pyrites, but there

was a great deal of oxidation of the coal, and now data had been obtained which threw a vivid light on the pyrites question. It was a great surprise to him that it was possible to take the unoxidizable crystalline Barnsley pyrites and, after pounding it to a powder, to find that it was just as oxidizable as the pyrites from the Bullhurst Seam of North Staffordshire. They had not yet gone into the vexed question as to marcasite and cubical pyrites, because it was desired at Doncaster to go direct to the point and ascertain to what extent the pyrites actually present was oxidizable, and exactly how much heat it produced. Those members of the Institution who were at the laboratory at Bentley in September, 1915, would remember a sample that Mr. Winmill had in a vacuum-flask, which was heating before their eyes at the rate of about a degree a minute. As far as he remembered, this was mainly ordinary Barnsley pyrites just pounded up, and yet it could be seen heating so rapidly that the thermometer could be detected moving if it were watched carefully, and the glass would have been fused in a very short time if the oxygen supply had not been cut off. That demonstration must have given an idea of the capacity of pyrites when the crystalline surface was broken. He fully agreed with Prof. Louis, however, that there was still a great deal to be found out concerning pyrites, although Mr Winmill had given much solid information in his paper.

Mr. R. W. DRON (Glasgow) asked whether, in carrying out his experiments, the author had dealt with the effect of pressure. The subject was suggested to him by Mr. Ellison's statement respecting the heap of coal that had taken fire, for he had recently had a similar experience. A heap of duff had been laid by until difficult times like the present. As long as the heap did not reach to a height of more than 10 or 12 feet there was no trouble, but as soon as it extended to 18 or 20 feet it began to heat. It was a poor substance, containing about 30 or 40 per cent. of ash, and not a material that one would have expected to give rise to spontaneous combustion: moreover, the seams from which it came had never caused trouble in any way. The only explanation that he could suggest to account for the occurrence was the extra pressure due to the height, because when 10 feet were taken off the top the heating immediately stopped.

The CHAIRMAN (Sir William Garforth) said that the papers contributed by Dr. Haldane, Mr. Winmill, and Mr. Graham marked the time for which many members of the Institution had waited, and no doubt they, like himself, welcomed the discussion that had taken place that afternoon.

They all knew that in the past large areas of coal had been abandoned owing to spontaneous combustion and the consequent dread of loss of life. He hoped that the detailed particulars of the investigations which had been given by the various writers, taken in conjunction with certain facts which the mining engineer had observed when actually dealing with difficulties underground, would result in better and safer methods being adopted. If, as a result of a further interchange of ideas between the scientist and the mining engineer, some additional precautions could be suggested and further loss of life be prevented, he thought that the members would admit that the papers in question would be amongst the most valuable that the Institution had received.

He had often stated that the dangers and difficulties of spontaneous combustion in coal-seams were far more serious than the dangers of coal-dust, for the former was due to natural causes, whilst the latter was artificially produced, and could easily be prevented by so diluting the coal-dust with shale or incombustible dust that the risk of explosion was removed. In the case of spontaneous combustion, however, he feared that, like himself, the majority of the members did not perfectly understand the phenomena in which physical, chemical, and mechanical actions all combined, and therefore he hoped that further discussion would lead to the suggestion and adoption of practical remedies.

Mr. T. F. WINMILL (New Whittington) said that he felt that he had taken the meeting at a disadvantage by not reading the papers in full, and this explanation perhaps applied more particularly to the remarks of Prof. Louis than to any of the others. Prof. Louis had pointed out that it was commonly known that there were two definite forms of pyrites. With that statement he agreed, but the statement was also commonly denied, and it was difficult to know where the truth lay. There seemed to be rather a division of opinion as to how far these two forms of pyrites were really different forms. In order not to obscure the

point at issue, it was stated definitely in the paper where the pyrites was taken from and how it had occurred in the seam, so that anybody who understood mineralogy could, in the light of the observations in the paper, determine whether the pyrites in the different seams was marcasite or true pyrites. So far as his experience went, within the limits of experimental error there was no difference in the heat productions of the two forms of pyrites. The heat productions described in the paper were investigated, not once, but many times, and samples were taken from different places, including Barnsley pyrites. He was not very much concerned with the non-oxidizable form, which might be called true pyrites. It gave the same results as the finely-divided Bullhurst pyrites, when ground to a fine dust, but did not cause fires in the pit. Prof. Louis had mentioned the difficulty in estimating the quantity of pyrites present, and he, the speaker, agreed that such an estimation was most difficult. If he had been able to read the paper in full, he would have pointed out that the only cases in which definite figures were given for the percentage of pyrites were those in which this percentage was very high—as a rule, as much as 80 per cent.—and in such cases it was fairly easy to estimate the sulphur and the iron by several methods. Nevertheless, he had had great difficulty in obtaining concordant results by different methods, but in general the argument was not in the least altered by an error of 1 per cent. in the amount of pyrites when the total percentage was so high. The degree of oxidation of the pyrites had been determined from the amount of sulphate produced, and that was quite a different sort of proposition; but in general the estimation of the pyrites in the coal was scarcely affected by errors in the analytical methods. He was very glad to find that someone else had had the same difficulty as that which he had experienced in trying to find out how much pyrites there was. He also confirmed Prof. Louis's statement that the sulphur was partly contained as an organic compound. For instance, in South Staffordshire coals the very least amount was 1 per cent., and if less than 1 per cent. was allowed as organic compounds the result was a negative quantity of ash in the coal, which was ridiculous. Mr. Mackey and he were apparently more at variance than was really the case. He himself was concerned really with a "sample" of a sample, and could therefore work

with accuracy on a very quantity of coal. Mr. Mackey, on the contrary, had to deal with a large mass of coal, of which he had to take an average sample. This necessitated a larger quantity being used in the analysis. For such an analysis it might well be that heating in an air-bath introduced no larger errors than might be introduced by the difficulties of sampling. As to the heating of a small sample in an air-bath being the correct method, there he and Mr Mackey were at variance, and he was sorry to hear Mr. Mackey argue that two processes giving the same result were, therefore, both accurate. That two methods gave the same result might mean that both were right, but it might also mean that both were wrong. In the paper reasons had been given for believing that the air-bath method was liable to error, and Mr. Mackey's experiments would therefore indicate that to dry coal at ordinary temperatures over sulphuric acid *in vacuo* was also a faulty method. His own experience agreed with this. It was very remarkable that dry coal absorbed moisture much faster than sulphuric acid, which was a very powerful desiccating agent. He had dried samples of coal *in vacuo* over sulphuric acid, and he believed that it was not until after about 28 days that he obtained a constant weight. He had taken the sulphuric acid out of the desiccator and put in at the bottom of the desiccator some dry coal instead of sulphuric acid, and then the dry coal had absorbed all the moisture from a small sample of coal in a few hours, thus showing that dry coal had a greater affinity for water under these conditions than sulphuric acid. With sulphuric acid there was very nearly dry coal in the desiccator and sulphuric acid at the bottom. Since dry coal absorbed moisture more quickly than sulphuric acid, the vapour pressure of water over the practically dry coal was less than the vapour pressure over sulphuric acid. If the vapour pressure was less over the dry coal, when that point was reached the sulphuric acid obviously should not take any more water out, otherwise they would have perpetual motion and that, Mr. Mackey would agree, was a *reductio ad absurdum*. Then, again, it had been shown in the paper that coal reacted with oxygen at 105° Cent., and he had there shown how in 10 minutes it lost its maximum weight of water, and after 10 minutes by absorbing oxygen had greatly increased in weight again. He wished to make it quite clear

that the criticism of the moisture determination did not apply to the ordinary routine determination of moisture. This had to take into account errors in sampling and various other difficulties which could not be conveniently overcome by the vacuum method; but for very accurate estimation of moisture the vacuum method should be adopted, especially if the coal had to be analysed afterwards in order to find out particularly the percentage of oxygen in it.

With regard to the firing of stacks of coal, Mr. Smith had mentioned that his stacks did not fire, but in this case he (Mr. Winmill) was not at all sure that the position of the stacks and the nature of them was not partly responsible for their non-liability to fire. They were placed on the top of a hill, more or less, there was a great deal of large coal, and there was a perpetual breeze blowing through the stack, so that it was very difficult for a stack to fire in those circumstances. They had heard that several people had had difficulty with stacks firing, and their experience was exactly parallel to the classic experience of Fayol, who found that heaps of coal from 10 to 12 feet high in general did not fire, but that as soon as the heap was about 18 feet high it almost invariably fired, unless it contained a special sort of coal that was not liable to fire. He did not think that the cause of the firing could be attributed to pressure. It was, he believed, a question of heat insulation. The heap must be a certain size before the centre of it was properly insulated, and moreover he had shown that the actual mechanism of firing might be rather a complicated business, depending rather on the distance that the air had travelled, the amount of water-vapour it contained, and questions like that. The instance mentioned by Mr. Mowat as to alkaline water running from an ironstone mine in which there was pyrites was certainly most remarkable. Normally, with the pyrites oxidizing the water would be acid.

Mr. Mowat pointed out that the ironstone mine was submerged, and the water was slightly alkaline now. When the mine was working the water was acid.

Mr. Winmill, continuing, said he did not think that there was anything definite about the variation of percentage of moisture in superior or inferior coals, and this opinion was borne out

in the case of the Barnsley Coal, which had a high percentage of moisture, but was certainly not an inferior coal.

In answer to a question from the Chairman, Mr. Winmill stated that he had not carried out any microscopical examination. Mr. Lomax had been to a colliery in the Doncaster district (he understood), to take samples of coal from some pillars filled with breaks, which had been exposed for about three years, so that their oxidation was complete.

The CHAIRMAN thought that it would be admitted that the work of the microscopist would prove most helpful in colliery science, as he could produce visible and permanent evidence of his work. He therefore hoped that the work of the microscopist, combined with that of the chemist, would be utilized by the mining scientists of the future, and lead to investigations being made that for want of this combination had not been possible in the past.

Mr. WINMILL claimed that he could produce definite information from laboratory methods. The microscopist had the advantage that he produced visible sections of the coal, whereas the results of chemical experiments would be contained perhaps in tables of figures. So far, they had not obtained very much information as to the relation of the chemical constitution of coal with the microscopical.

Prof. L. T. O'SHEA (Sheffield University) said that he would like to mention a small point which perhaps confirmed what Mr. Winmill had said with regard to the equilibrium between the amount of moisture given off by coal and that absorbed by sulphuric acid. In his experience he had found, time after time, that it was possible for dry coal to absorb moisture from sulphuric acid. They could take a sample of coal dried in the oven, and, after allowing it to stand overnight in a desiccator over sulphuric acid, it would be found the next morning to have absorbed moisture.

Mr. JAMES ASHWORTH (Vancouver, B.C.) wrote that the papers raised the old question of the real cause of "gob-fires" or spontaneous combustion in coal-mines and in stacked coal on the surface. At one time the writer was of opinion that the

iron pyrites in the coal was responsible for the trouble, but later, in view of the fact that heating and fires occurred in mines where the presence of pyrites was not very noticeable, and that fires did not arise in some mines where iron pyrites was present in quantity, his opinion had veered round to the oxidation-of-coal theory. He also concluded that another factor had to be taken into account, namely, moisture, and finally that no gob-fire would occur in a mine if it were dry—more particularly if the air were dry.

The writer well remembered the late G. C. Greenwell telling him that the owners of the Poynton Collieries used to stack a considerable tonnage of coal at Stockport railway-station ready for the winter trade, and that fires often occurred in the heaps. Mr. Greenwell came to the conclusion that these fires could be prevented by keeping the stacks of coal under 13 feet high, and this course, when adopted, proved effective. About this time the writer was connected with a colliery that was subject to gob-heating, and he noticed that the coal when stacked on the surface produced spontaneous combustion, which generally occurred soon after the first heavy shower of rain. His next experience was in a different district, where the coal was worked by the longwall method and on the end. Here he noticed that gob-fires never occurred at the lower end of the faces, which had a dip of about 1 in 4, and that the greatest trouble was from, say, three parts up the face to the top. The cause appeared to arise from the " sweat " settling on the gob, which when covered up by fine slack and dirt setting up heating. He was confirmed in this idea by an experience related by the late C. J. Homer, who stated that in a North Wales colliery where he had much trouble with gob-fires it had been noticed that, when the ventilating furnace was eased down at week-ends, the dampness in the air condensed on the gob as dew, and that when the miners commenced work and the gob was covered with fresh small coal and dirt, heating resulted. Later on mechanical ventilation was adopted, and gob-fires then either ceased or were less frequent. With these experiences in mind the writer came to the conclusion that damp air was a necessary factor in the starting of gob-fires, and that the best means of preventing such fires was to keep the air as dry as possible and to bring it downhill instead of uphill.

Spontaneous fires used to occur frequently at a colliery near Church Gresley railway-station. The colliery was both damp and wet, and yet the writer was informed that a small heap of slack coal left in the return airway over night had been known to heat up, if not fire, in a very few hours. Was it not a fact that most gob-fires occurred in soft friable coal-seams having a high percentage of ash and moisture? The writer had in consequence looked upon damp air as being a necessary factor in any coal-mine where spontaneous outbursts of fire were of frequent occurrence. This opinion was borne out by Mr. Winmill's statement that "a coal which contains both a high percentage of moisture and a high percentage of oxygen is usually more oxidizable than one with low oxygen and low moisture"; and that "the quantities of oxygen and moisture already in the coal do not themselves influence the absorption of oxygen, but are indications of the presence of other compounds in the coal substance which are easily oxidized."

In conclusion, the writer would suggest to those working mines subject to "gob-fires" to keep the ventilating air-current as dry as possible, and to run the fan nearly as fast at the week-end or "play" days as when the mine was in full work.

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Prof. F. W. HARDWICK then delivered a lecture on the "History of the Safety-lamp," based on the following paper by himself and Prof. L. T. O'Shea:—

# NOTES ON THE HISTORY OF THE SAFETY-LAMP.

By F. W. HARDWICK, M.A., AND L. T. O'SHEA, M.Sc.

## I.—INTRODUCTORY.

The writers undertook to prepare a paper on "The History of the Safety-lamp" for the International Congress of Mining, Metallurgy, Applied Mechanics, and Economic Geology, which was to have been held in London in July, 1915, that year being the centenary of the invention of the Davy safety-lamp. Bearing in mind the character of the Congress, they endeavoured to extend their investigations beyond the history of the safety-lamp in Great Britain, and also to include, as far as they were able, the progress made in other countries in matters relating to the safety-lamp. As the South Shields Committee wrote in their Report in 1843, with reference to the Belgian lamps tested by them: "Genius and humanity are exclusively of no country"; and while Great Britain can claim the inventors of the earliest safety-lamps, and has participated in the improvements which have been made subsequently in safety-lamps, yet to the progress which has taken place other countries interested in coal-mining have contributed, notably Belgium and France.

The history of the safety-lamp does not appear to have received as much attention as might have been expected. In so far as the subject belongs to the history of coal-mining, the earlier part of it has been dealt with already by Mr. R. L. Galloway in his *Annals of Coal Mining* far more comprehensively than is possible for the writers in the restricted space of a paper. Mr. Galloway has entered minutely into the events which led up to the invention of the safety-lamp, into the Davy-Stephenson controversy, and into the position occupied by the safety-lamp in later years. The subject has been more briefly touched on by other writers, while complete descriptions of many forms of lamp, especially those of more recent date, are given in various monographs on the safety-lamp, in text-books on mining,

and in papers published by British and foreign societies interested in mining.

The writers have found it difficult to compress the large amount of available information on the subject. For this reason little has been said on the comparative safety of the various lamps mentioned, on the work of the various Commissions and Committees which have investigated the subject; or on the design of many lamps. A detailed description has been given of the earliest lamps of each type, and of some lamps respecting which information is difficult to find. Lamps of later date, information about which is more easily accessible, have been less closely described. For the same reason little has been said about such important matters as the locking of lamps, contrivances for preventing lamps from being opened, the illuminants used, methods of lighting and re-lighting lamps, questions affecting the size and construction of the wire-gauze, the proportions to be observed in the parts of lamps, or the improvements which have been effected in the construction of lamps. Electric lamps have been omitted altogether, since they depend for their operation and safety on principles entirely different from those of the flame-lamp. Contrivances for detecting firedamp by other means than the flame test have been omitted for a similar reason.

In dealing with so large a subject, it is impossible to suppose that omissions have not been made, and the writers hope that members of the Institution will assist by supplying such information as may be necessary to make the record complete. The part played by Great Britain in the invention and improvement of the safety-lamp is an episode in its history of which the country has every reason to be proud, and it would seem advisable that the Institution should possess as complete and as accurate a record of it as is possible.

The writers wish to express their thanks to all those who have kindly permitted them to reproduce illustrations of various forms of safety-lamp—and especially to the Royal Society and to the Royal Society of Arts. They desire also to thank Dr. J. B. Simpson, Mr. J. R. R. Wilson, and Mr. James Barrowman for their kindness in looking over the proof-sheets, and Mr. F. Schmidt for revising the portion of Section XIV. relating to Belgium and France. They must also acknowledge the great

assistance and courtesy that they have received from the authorities and officials of the Science Museum, South Kensington; from the Secretary and Librarian of the Royal Society, and of the Royal Society of Arts; and from the officials connected with the Libraries of the British Museum, the Patent Office, the Museum of Practical Geology, the Institution of Civil Engineers, the Institution of Mining Engineers, and the North of England Institute of Mining and Mechanical Engineers.

The extracts from various publications of the British Government, and illustrations of safety-lamps from the *Final Report of the Royal Commission on Accidents in Mines*, 1886, have been reproduced by permission of the Controller of H. M. Stationery Office.

## II.—The Lighting of Coal-mines Previous to the Invention of the Safety-lamp.

The earliest detailed references to the explosive nature of firedamp appear to occur in the latter part of the 17th century, some of them in the earlier numbers of the *Philosophical Transactions** of the Royal Society. From these accounts it appears that the danger from firedamp was well known, and that the risk of ignition of the gas by the candle, by the snuff of the candle, or by sparks, was fully appreciated. Explosions of firedamp, fatal to life, had already occurred, but lives had been saved by the men "lying flat on their bellies." Ventilation—"to keep the air very quick"—seems to have been the chief preventive, but in Somerset "single-wick" candles, 60 or 70 to the pound, were used in dangerous places, and were put behind the workmen, away from the "breast of work." The indication of the presence of gas furnished by the candle appears to have been understood.

* In 1666 the Hon. Robert Boyle contributed an enquiry, "Articles of Inquiry touching Mines," to the *Philosophical Transactions* of the Royal Society (vol. i., No. 19, page 330), in which various questions were asked relating to the conditions of mining, including the "Damps" and the atmosphere of mines.

Replies were sent by Mr. Lister and Mr. Jessop relating to North Derbyshire (*Ibid.*, 1675-1676, No. 117, page 391; No. 119, page 450); by Mr. Roger Mostyn relating to Flintshire (*Ibid.*, 1676-1683, No. 136, page 895); and by Mr. J. Beaumont relating to "Some Coal-works bordering on the Mendippe Hills" (*Philosophical Collections of the Royal Society*, by Robert Hooke, 1679, No. 1, page 6).

Information respecting the particulars given in these papers will be found in *The Annals of Coal Mining*, first series, by R. L. Galloway.

The Hon. Roger North,* writing of coal-mines in the North of England, stated that "an infallible trial is by a Dog, and the candles show it," that is, "Damps or Foul Air." In Flintshire firing the gas by firemen before work commenced was practised.

Although during the 18th century the explosive nature of firedamp came to be fully and widely recognized, no remedy other than by ventilation was forthcoming, and as the output of coal increased, and the workings were carried deeper and became more extensive, accidents from this cause became more frequent. That they were not more common was probably due to the experience and skill of the workmen, who used their candles, not only for furnishing light, but also for indicating the presence of the gas. Mr. John Buddle, in his letter written on October 18th, 1813, from "Wall's End" Colliery to the Society in Sunderland for Preventing Accidents in Coal Mines, gave a very interesting account of testing for gas with the candle. He pointed out that every quantity of the gas, from the slightest mixture to the firing point, could be discerned by the experienced collier from observation of the appearance of the spire upon the top of his candle.

"The common pit candles vary in size, but those generally used are forty-five to the pound; the wick is of cotton, and the candle made of ox or sheep tallow; but clean ox tallow is the best.

"The mode of trying the candle, as it is called, to ascertain the mixture of inflammable gas, is as follows:—

"In the first place, the candle, called by the colliers the 'low,' is trimmed, that is, the liquid fat is wiped off, the wick snuffed short, and carefully cleaned of red embers, so that the flame may burn as purely as possible.

"The candle being thus prepared, is holden between the fingers and thumb of the one hand, and the palm of the other hand is placed between the eye of the observer and the flame, so that nothing but the spire of the flame can be seen, as it gradually towers above the upper margin of the hand. The observation is generally commenced near the floor of the mine, and the light and hand are gently raised upwards, till the true state of the circulating current be ascertained.

"The first indication of the presence of inflammable air is a slight tinge of blue, or bluish grey colour, shooting up from the top of the spire of the candle, and terminating in a fine extended point. This spire increases in size, and receives a deeper tinge of blue as it rises through an increased proportion of inflammable gas, till it reaches the firing point; but the experienced collier knows accurately enough all the gradations of 'shew' (as it

* *The Life of the Right Honourable Francis North, Baron of Guilford, Lord Keeper of the Great Seal*, by the Honourable Roger North, Esq., 1742, page 135. Mr. North's remarks would apply to either firedamp or blackdamp; but he seems to have referred to the former gas, as he went on to say: "The flame of a candle will not kindle them so soon as the snuff, but they have been kindled by the striking fire with a tool. The blast is mighty violent."

is called) upon the candle, and is very rarely fired upon, excepting in cases of sudden discharges of inflammable gas.

"The shew upon the top of the candle varies very much according to the length of run, or distance, which the current of air has passed through, before it is mixed with the inflammable gas. The shorter the run of the current of air, before it is mixed with the inflammable gas, the less will be the shew upon the candle when at the firing point, and *vice versâ*."*

Besides candles, various forms of lamp were used for lighting. In 1684 Edward Wyndus took out a patent "for the great and durable increase of light by extraordinary glasses and lamps . . . . for the . . . . dispersing of light in mines," but this invention does not appear to have been intended to deal with the danger from firedamp.

Between the years 1730 and 1750, the flint-and-steel mill was invented by Mr. Carlisle Spedding of Whitehaven.† The date is given by some writers as 1760, but this is probably derived from Mr. John Buddle's statement that about 1760 flint-and-steel mills were introduced into the collieries on the Tyne and Wear. Allusion is made to the instrument in a poem‡ by John Dalton, D.D., published in 1755:—

"Nor strikes the flint, nor whirls the steel
Of that strange spark-emitting wheel,
Which, formed by Prospero's magic care,
Plays harmless in the sulphurous air,
Without a flame diffuses light
And makes the grisly cavern bright."

A foot-note stated that "Prospero" was Mr. Spedding.

Sir James Lowther, in a paper contributed to the Royal Society in 1733-1734§ on the "Damp Air" encountered in a sinking pit, wrote—

*This description was quoted also by Mr. Nicholas Wood, in a paper on "Safety-lamps," in the *Transactions of the North of England Institute of Mining Engineers*, 1852-1853, vol. i., second edition, page 301.

†*The History of the County of Cumberland*, by William Hutchinson, F.A.S., 1794, vol. ii., pages 57, 69, and 70; *The Literary Life of William Brownrigg, D.D., F.R.S.*, by Joshua Dixon, M.D., 1801, page 104; *The Victoria History of Cumberland*, edited by James Wilson, M.A., 1905, vol. ii., page 357.

‡*A Descriptive Poem addressed to two Ladies at their return from viewing the Mines near Whitehaven, by* John Dalton, D.D., 1755. The poem was written about 1753, and commences—

"Welcome to light, advent'rous pair!
Thrice welcome to the balmy air
From sulphurous damps in caverns deep,
Where subterranean thunders sleep."

It is reproduced in Hutchinson's *History of Cumberland*, vol. ii., page 54.

§*Philosophical Transactions* of the Royal Society, vol. xxxviii., No. 429, page 109, iii.

"It is to be observed that this sort of Vapour or damp Air will not take fire except by Flame; Sparks do not affect it, and for that Reason it is frequent to use Flint and Steel in Places affected with this sort of Damp, which will give a glimmering Light that is a great Help to the Workmen in difficult Cases."

As Mr. R. L. Galloway has remarked, however, this may not refer to the flint-and-steel mill, but to some earlier method of using these substances, on which Mr. Spedding's invention may have been an improvement.

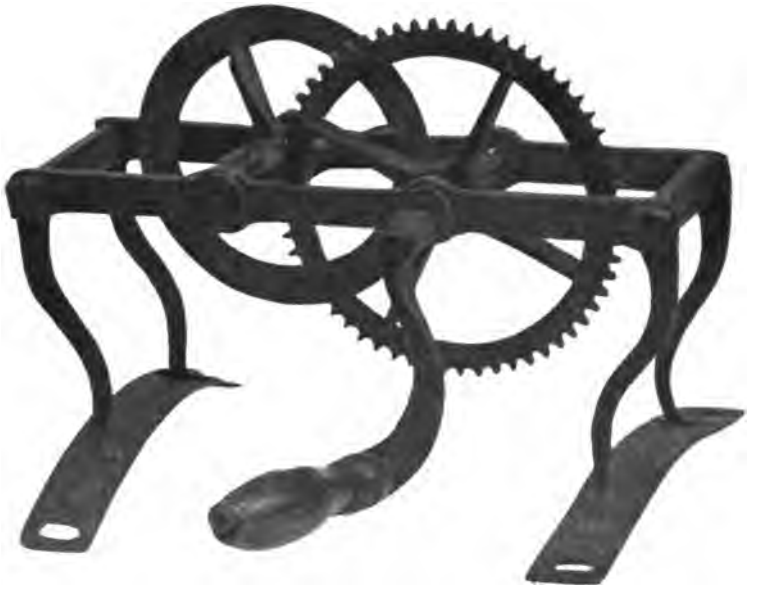

FIG. 1.—FLINT-AND-STEEL MILL.
The original of this mill is in the possession of the University of Sheffield.

Mr. John Buddle in the "letter" already referred to, written in 1813, gave the following description of the flint-and-steel mill (Fig. 1):—

"An instrument for striking light with flint and steel. A brass wheel above 5 inches in diameter, with fifty-two teeth, works a pinion with eleven teeth. On the axle of the latter is fixed a thin steel wheel, from 5 to 6 inches in diameter. The wheels are placed in a light frame of iron which is suspended by a leather belt round the neck of the person who plays the mill. Great velocity is given to the steel wheel by turning the handle of the toothed wheel, and the sharp edge of a flint is applied to the circumference of the steel wheel, which immediately elicits an abundance of sparks, and emits considerable light."

The sparks gave indications of the presence of inflammable gas by increase in size and luminosity; on approaching the

firing-point they assumed a liquid appearance, and adhered more than usual to the periphery of the wheel, giving off a bluish light. When the quantity of firedamp present was in excess of the explosive limit, or in carbonic-acid gas, the sparks were "of a bloody-red colour."

The flint-and-steel mill appears to have been known on the Continent of Europe. M. Boisse mentioned its employment in the mines at Liége;* and it was referred to by Prof. Bischof of Bonn,† and by Baron Friedrich Alexander von Humboldt in his work on *Mine Gases*, published in 1799, but the two last-named references do not necessarily imply that it was used in Germany.

According to Dr. Clanny, steel mills cost about a guinea each, and it required the constant employment of one workman to keep six of them in repair.

Those intimately connected with the management of collieries seem to have been fully aware of the limitations of the contrivance. Mr. Buddle stated that the first explosion distinctly known to have taken place at the "steel mill" was at Wallsend on June 9th, 1785,‡ and that, although he had never witnessed an explosion from the sparks given off by the instrument (this was in 1813), yet "the inflammable air has frequently fired at the sparks of the steel mills, but only when they are played near the place where the hydrogen gas is discharged." Mr. Matthias Dunn also stated that the flint-and-steel mill "has frequently been known to produce explosion.§"

In 1796 Klinger, of Breslau, invented a miner's lamp on the lines of one already suggested by Baron Friedrich Alexander von Humboldt. In 1799 von Humboldt published his book‖ on

* *Mémoires Couronnés, Académie Royale de Belgique*, 1840, "Des Moyens de Soustraire l'Exploitation des Mines de Houille aux Chances d' Explosion," page 92; "Mémoire sur les Explosions dans les Mines de Houille et sur les Moyens de les Prévenir," by M. A.-A.- M. Boisse, Ingénieur des Mines à Carnaux (Tarn).

† *Ibid.*, page 310, "Mémoire sur l'aérage des Mines," by M. Gustave Bischof, Professeur de Chimie et de Technologie à l'Université de Bonn.

‡ Mr. Buddle, *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835. In his reply to Question No. 3,003, Mr. Buddle gave a list of explosions which had occurred in the North of England from 1658 to 1835, and in this the date of the explosion at Wallsend is given as June 9th, 1785. In his reply to question No. 2,489, Mr. Buddle gave the year as 1783, but in his list no explosion at Wallsend is entered as having occurred in 1783, although there was one in 1782, and two in 1784.

§ *A Treatise on the Winning and Working of Collieries*, by Matthias Dunn, 1848, page 167.

‖ *Ueber die unterirdischen Gasarten und die Mittel ihren Nachtheil zu vermindern*, by Friedrich Alexander von Humboldt, 1799.

the mine gases, in which he gave descriptions and illustrations of lamps which he had invented, which were intended to burn in gases that would extinguish the flame of an ordinary lamp or candle, and were supplied with air from a reservoir. These lamps were no doubt intended to be used also in connexion with a respirator form of life-saving apparatus, which was described in the book.

M. Boisse,* writing in 1840, remarked that the lamp left something to be desired on the score of safety, and would have required so large an air-reservoir as to be very cumbersome. He mentioned that von Humboldt used the lamp himself in a very dangerous mine in the country of Anspach, with very good results.

In order to avoid the risk of danger involved in using a naked light in the presence of firedamp, phosphorescent materials were tried—"phosphoric lights," fish in a state of incipient putrescence, and "various other schemes."†

"Amadou, or fungus tinder," was occasionally used in the dangerous parts of the mines in Flanders.‡

Mirrors were employed in some cases in sinking shafts through strata in which large quantities of firedamp were encountered, or in executing repairs under similar circumstances. Mr. John Buddle stated§ that this was suggested accidentally by the reflection of the sunlight at the bottom of a shaft from the saw of a carpenter who was working on the sheer-legs at the top, and that he had used mirrors to give light in repairing the shaft at Percy Main Colliery. Mr. Matthias Dunn alluded to the use of a mirror in sinking Murton West Pit, in which candles could not be used on account of a blower of gas.

Even after the invention of the safety-lamp, Mr. Goldsworthy Gurney proposed to light the workings of collieries by light reflected from the surface by means of mirrors, and his scheme was investigated by the Select Committee on Accidents in Mines, 1835.

* *Op. cit.*, page 93.

† Mr. John Buddle, *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 2,487.

‡ *The Collected Works of Sir Humphry Davy, Bart., LL.D., F.R.S.*, edited by his brother, John Davy, M.D., F.R.S., 1840, vol. vi., page 9.

§ *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 2,489.

In 1805 Dr. Thomas Trotter, of Newcastle-upon-Tyne, formerly physician to His Majesty's Fleet, published *A Proposal for Destroying the Fire and Choak Damps of Coal Mines*, in which he suggested that these gases should be destroyed by the action of "oxygenated muriatic gas" or by "nitrous acid." These proposals were strongly criticized by Dr. Henry Dewar, of Manchester, and by a "friend of rational schemes of improvement."

## III.—GROWTH OF KNOWLEDGE AS TO THE COMPOSITION AND PROPERTIES OF FIREDAMP.

In a "letter" printed in the *Philosophical Transactions* of the Royal Society for 1675-1676,* Mr. Jessop of Broomhall attempted a rough kind of classification of the "damps" found in the Derbyshire collieries. Dr. William Brownrigg† stated that "the firedamp first attracted the notice of philosophers in 1733." In that year Sir James Lowther sent bladders filled with gas, collected from the collieries at Whitehaven, to the Royal Society for examination, in connexion with his paper already mentioned.

Mr. John Maud‡ in 1736 made "an artificial firedamp" by acting on iron filings with oil of vitriol and "common water;" he collected the "fumes," and found that they exhibited a flame like that of the gas sent by Sir James Lowther. The artificial gas resembled the natural gas in smell, although it differed from it in the colour of the flame; when mixed with air, it was explosive.§

Dr. Brownrigg himself took great interest in the "damps" found in the Cumberland coal-mines. He considered that firedamp possessed similar properties to hydrogen gas, although its specific gravity was greater: he was aware that it was lighter

* *Philosophical Transactions* of the Royal Society, 1675-1676, vols. x. and xi., No. 117, page 391.

† In a publication entitled *An Account of the Coal Mines near Whitehaven*, which was reproduced in *The Literary Life of William Brownrigg, M.D., F.R.S.*, by Joshua Dixon, M.D., 1801, pages 103-104.

‡ "A Chemical Experiment, by Mr. John Maud, to illustrate the Phenomena of the Inflammable Airs shown to the Royal Society by Sir James Lowther, Bart.," *Philosophical Transactions* of the Royal Society, 1735-1736, vol. xxxix., No. 442, page 282, vi.

§ The gas so produced was hydrogen, not marsh-gas ($CH_4$). When hydrogen is produced in this way, it possesses an unpleasant smell, usually attributed to the presence of volatile hydrocarbons derived from the carbon contained in the metal.

than atmospheric air. He erected a laboratory* near Whitehaven, into which firedamp was conducted from an adjacent pit through a lead pipe, and on his retirement proposed to write a history of "damps," but he only wrote the outlines.

In 1739 an account of the analysis of some coal obtained from a place about 2 miles from Wigan by the Rev. John Clayton, D.D., was contributed to the *Philosophical Transactions*.† Dr. Clayton, on distilling this coal in a retort on an open fire, found that "at first there came over only Phelgm, afterwards a black Oil, and then likewise a Spirit arose, which I could in no ways condense." This "Spirit" proved to be an inflammable gas.

In 1763 the explosive nature of firedamp was brought under the notice of the Académie Royale des Sciences in Paris, in consequence of an explosion which occurred in that year in a coal-mine near Briançon. The Academy issued a very interesting report,‡ in which the occurrence of the gas in "Haynault," and in various parts of England, was noticed; it was, however, unable to suggest any remedy, except by increasing the ventilation. Allusion was also made to the practice of firing the gas.

According to Profs. Roscoe and Schorlemmer,§ Volta in 1776 pointed out the difference between hydrogen and marsh-gas, but firedamp continued to be spoken of as "hydrogen" in ordinary parlance for many years later. In 1785 Berthollet proved that marsh-gas contained both carbon and hydrogen, although it was not until 1805 that Dr. William Henry distinguished between it and olefiant gas. Even at that date the occurrence of firedamp underground was not understood. Dr. Henry Dewar, in 1806, stated‖ that the common explanation of firedamp was that it was produced "by the decomposition of water by means of the native sulphuret of iron, commonly called iron

* *The Literary Life of William Brownrigg, M.D., F.R.S.*, by Joshua Dixon, M.D., 1801, pages 7-9. Dr. Dixon stated that Dr. Brownrigg contributed a paper to the Royal Society in 1741, which was presented by Sir James Lowther, and another in 1746, describing his laboratory near Whitehaven.

† *Philosophical Transactions* of the Royal Society, January to March, 1739, vol. xli., part i., page 59.

‡ "Sur les Matières inflammables qui se trouvent dans les Mines de Charbon de Terre, et sur les Moyens de s'en garantir," *Abrégé de l'Histoire et des Mémoires de l'Académie Royale des Sciences*, 1763, vol. xiii., page 71.

§ *Treatise on Chemistry*, 1878, vol. i., page 607.

‖ *A Letter to Thomas Trotter, M.D., occasioned by his Proposal for Destroying the Fire and Choak Damps of Coal Mines*, by Henry Dewar, M.D., one of the Physicians to the Manchester Infirmary, page 15.

pyrites;" the oxygen in the water converted the iron pyrites into sulphate of iron, and, in the process, the hydrogen of the water was liberated. Dr. Thomas Trotter* supposed that firedamp was "hydrogen evolved from water in consequence of the union of the oxygen of the water with the carbon of the coal," the other product being carbonic-acid gas. In 1808 Dr. Henry contributed a paper to the Royal Society giving a description of an apparatus for the analysis of compound inflammable gases by slow combustion, with examples drawn from the coals of various British coalfields. It is interesting to notice that this paper was communicated to the Royal Society "by H. Davy, Esq.," Secretary to the Society.

In 1814, at the request of the Home Office, the Royal Society appointed a committee† to examine certain matters connected with lighting by coal-gas. Dr. Wollaston and Mr. Tennant conducted experiments for this committee, and ascertained "that flame cannot be communicated through a pipe of the size used for supplying the lamps, in coal-gas mixed with any proportion from one to five times its bulk of air;" also that coal-gas required to be mixed with a large quantity of "common air" to cause explosion—"they found that with less than five times its volume of common air it would not explode; and that for the briskest explosion, about twice that quantity was required." Further on in the Report of the committee, it was remarked that "the dreadful destruction made by the fire-blast in coal-pits is owing to a gas nearly of the same kind." Sir Humphry Davy was not aware of these experiments, as he was abroad at the time.

## IV.—The Society in Sunderland for Preventing Accidents in Coal Mines.

The history of the safety-lamp may be said to commence in 1813, for in that year the Society in Sunderland for Preventing Accidents in Coal Mines was formed, which led directly to Sir Humphry Davy's experiments and to the invention of the Davy safety-lamp. In the same year Dr. William Reid Clanny invented his first safety-lamp.

* *A Proposal for Destroying the Fire and Choak Damps of Coal Mines*, by Thomas Trotter, M.D., late physician to His Majesty's Fleet, 1805, pages 8-9.

† Report included in the *Report from the Select Committee on Gas Light Establishments*, July 7th, 1823.

On May 25th, 1812, an explosion of firedamp occurred at Felling Colliery, also styled Brandling Main Colliery, at Felling, in the chapelry of Heworth, in the parish of Jarrow, County Durham, in which ninety-two men and boys were killed. The incumbent of Jarrow and Heworth at the time was the Rev. John Hodgson, M.A. (afterwards Vicar of Hartburn),* who was deeply grieved by the disaster, and much interested to see whether some remedy could not be discovered. In the hope of arousing the interest of scientific men, he wrote several notices of the explosion to the *Newcastle Courant*, and also published separately a full account of the explosion with a plan of the colliery.

At the time of this explosion, Mr. James John Wilkinson of 1, Pump Court, Temple, London, was in the neighbourhood. In his evidence before the Select Committee on Accidents in Mines,† 1835, he mentioned that he was much struck by the procession of ninety coffins‡ (ninety-one bodies were recovered; one body was never found), and on September 1st, 1813, he made proposals for the formation of a society for the prevention of accidents in coal-mines. These proposals came to the notice of the Bishop of Durham (the Hon. Shute Barrington, D.D.), who wrote to Dr. Gray, the Rector of Bishop Wearmouth (afterwards Bishop of Bristol), giving him full sanction to proceed with the formation of such a society. So that to the efforts of the Rev. J. Hodgson and of Mr. J. J. Wilkinson was due the formation of the "Society in Sunderland for Preventing Accidents in Coal Mines," which was instituted on October 1st, 1813, and held its meetings at the Sunderland Library. The Patron of the Society was His Grace the Duke of Northumberland, and there were sixteen Vice-Patrons; the President was Sir Ralph Milbanke, Bart., and Mr. W. Burn was Secretary and Treasurer. The permanent committee consisted of the above and twenty-eight others, among whom were the Rev. Robert Gray, D.D., the Rev. John Hodgson, William Reid Clanny, M.D., Mr. James

* *A Memoir of the Life of the Rev. John Hodgson, M.A., Vicar of Hartburn*, by the Rev. James Raine, M.A., Rector of Meldon, 1857, vol. i., page 90. A plan of Felling Colliery was given in the *Transactions of the North of England Institute of Mining Engineers*, 1853-54, vol. ii., second edition, page 33.

† *Minutes of Evidence*, Question No. 285.

‡ Five interments took place on May 27th, 1812, and the remainder between July 8th and September 19th (*A Memoir of the Life of the Rev. John Hodgson, M.A., Vicar of Hartburn*, by the Rev. James Raine, M.A., 1857, vol. i., page 98).

John Wilkinson, Mr. John Buddle, and Mr. Matthias Dunn.* The Society was supported by voluntary subscriptions, and it was intended to form a fund to award premiums for the discovery of new methods of lighting and ventilating mines.† In November, 1813, the committee presented its first report, which contained a letter from Mr. John Buddle, in which a very interesting account was given of the conditions that prevailed at the time in the collieries of the North of England. Mr. Buddle expressed the opinion that nothing further could be done to prevent explosion by the application of mechanical agencies, and that the only remedy lay in the discovery of some chemical method for rendering firedamp harmless as it was discharged; consequently, the Society had to look to scientific men for assistance in providing "a cheap and effectual remedy."

Mr. Holmes‡ stated that this opinion of Mr. Buddle's "threw a damp upon the exertions of the Society," but they appear to have acted on the suggestion, as Mr. J. J. Wilkinson made an attempt to approach Sir Humphry Davy on the subject. This attempt was unsuccessful at the time, but was renewed in the summer of 1815, with most fortunate results.

The Sunderland Society appears to have steadily pursued the object for which it was formed, until the invention of the Davy safety-lamp. Dr. Clanny stated in his evidence before the Select Committee on Accidents in Mines (1835)§ that "in the mind of the Rev. Dr. Gray," the invention of the Davy safety-lamp was sufficient reason for ending the proceedings of the Sunderland Society; "in others it was not." Dr. Clanny was evidently of the latter opinion, for, writing in 1844‖, he mentioned the Society "of which I am at present the Secretary and Treasurer." The work accomplished by it in connexion with the invention of the Davy safety-lamp entitles the Society to be gratefully remembered by all interested in coal-mining.

* A complete list is given in the first report of the Society, published in 1814; in *A Treatise on the Coal Mines of Durham and Northumberland*, by J. H. H. Holmes, 1816, page 147; in *The Annals of Coal Mining*, by R. L. Galloway, first series; and in the *Annals of Philosophy*, by Dr. T. Thomson, 1814, vol. iv., page 315. Matthias Dunn, in his book *A Treatise on the Winning and Working of Collieries*, 1848, gave a short account of the Society, page 179.

† *A Treatise on the Coal Mines of Durham and Northumberland*, by J. H. H. Holmes, 1816, page 149. ‡ *Op. cit.*, page 154.

§ *Minutes of Evidence*, Question No. 330.

‖ *Priority of the Invention of the Safety Lamp*, by W. Reid Clanny, M.D., 1844, *Gateshead Observer* Office; *Mining Journal*, 1844, vol. xiv., page 22.

## V.—Dr. Clanny.

William Reid Clanny, M.D.,* was born at Bangor, County Down, Ireland, in 1776. He studied medicine at the University of Edinburgh, and, after acting as Assistant Surgeon in the Royal Navy, he settled down in practice at Bishop Wearmouth, near Sunderland. He was physician in ordinary to the Duke of Sussex, and was the author of some works on medical subjects. In 1810 his attention was drawn to the subject of explosions of firedamp in collieries, and he was a member of the Society in

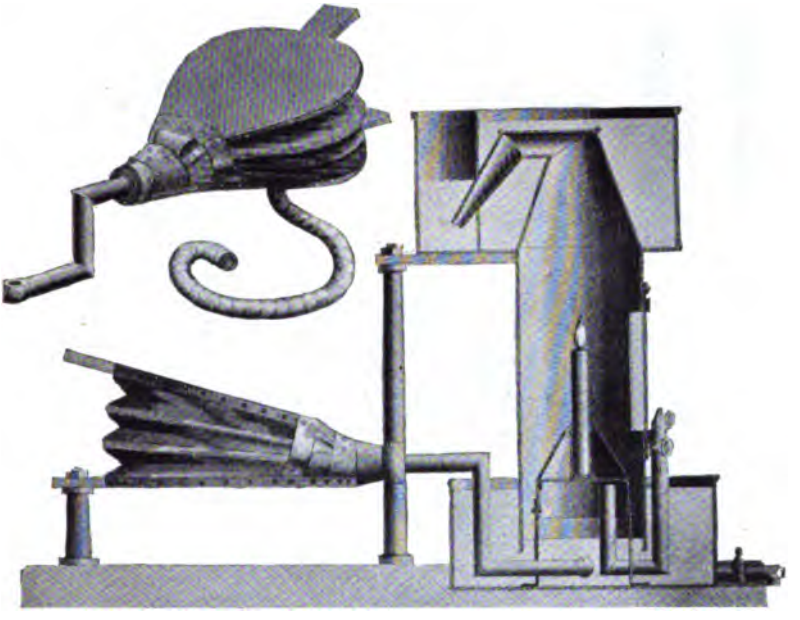

Fig. 2.—Dr. Clanny's First (Blast) Lamp.
Reproduced by permission of the Royal Society from the *Philosophical Transactions*, 1813, plate xv., page 205.

Sunderland for Preventing Accidents in Coal Mines. On May 20th, 1813, he contributed a paper on his newly invented safety-lamp to the Royal Society entitled "On the Means of Procuring a steady Light in Coal Mines without the Danger of Explosion."†

From this time until his death Dr. Clanny devoted great attention to the subject of giving a safe light to coal-miners at their work. He invented a number of lamps, of which the blast lamp, and the well-known "Clanny" lamp, in which the

* Further details of Dr. Clanny's life will be found in *The Dictionary of National Biography*; and in the *Mining Journal* for January 26th, 1850.

† *Philosophical Transactions* of the Royal Society, 1813, page 200.

flame was surrounded by a glass cylinder, surmounted by a gauze of Davy shape, are those best known; six of these lamps will be described in this paper.

Dr. Clanny's first lamp (Figs. 2 and 3)*—the Blast lamp—had a cistern of water above and below the light, which was contained in a kind of lantern. Air was forced in by bellows through the lower cistern, while the products of combustion passed out at the top of the lamp through a chimney, which narrowed down at the end furthest from the lamp almost into the shape of a pipe, and was bent down so that its extremity

FIG. 3.—DR. CLANNY'S FIRST (BLAST) LAMP.
Reproduced by permission of the Royal Society from the *Philosophical Transactions*, 1813, plate XV., page 205.

came below the level of the water in the upper cistern. Thus the air entered and left the lamp through water. The lamp was made of copper or block tin, and the light of the candle shone through a glass window. It may be presumed that this was the lamp which Dr. Clanny stated "was for some time at Wallsend and Leefield Collieries,"† and was exhibited to the members of the Literary and Philosophical Society of Newcastle-upon-Tyne and

* Much information as to Dr. Clanny's earlier lamps is given in *A Treatise on the Coal Mines of Durham and Northumberland*, 1816, by J. H. H. Holmes, pages 112-206.

† *Priority of the Invention of the Safety Lamp*, by W. Reid Clanny, M.D., 1844, *Gateshead Observer* Office, page 6.

to those of the Society in Sunderland for Preventing Accidents in Coal Mines.

The lamp was tested at the surface at Harrington* Mill Pit on October 16th, 1815, before Messrs. J. H. H. Holmes, William Patterson, Joseph Cleghorn, Anthony Hopper, and George Patterson, at the mouth of the upcast shaft, where firedamp was piped to the surface from the Hutton Seam. On November 20th, 1815, tests were conducted underground in a staple communicating with the Hutton Seam, in the presence of

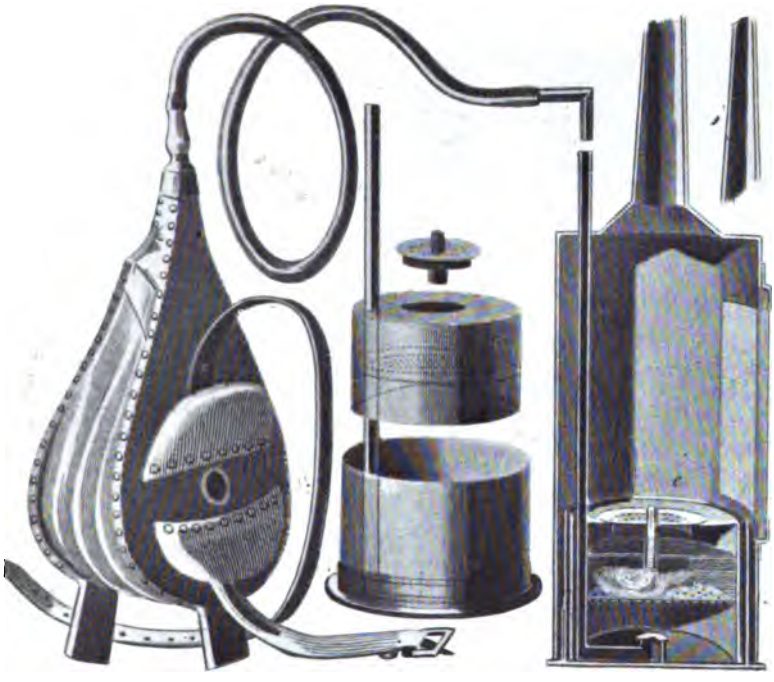

FIG. 4.—DR. CLANNY'S BLAST LAMP (SECOND FORM).

Reproduced by permission of the Royal Society of Arts from their *Transactions*, 1816, vol. xxxiv., plate vii.

Messrs. J. H. H. Holmes, W. Patterson, and Jno. Birkbeck. Gas was so abundant that candles could not be taken close to the staple: when the bellows were set to work in the explosive mixture, a slight flash occurred in the body of the lamp, and the candle was extinguished.† Mr. Holmes also mentioned that the

* Also spelt "Herrington."

† *A Treatise on the Coal Mines of Durham and Northumberland*, by J. H. H. Holmes, 1816, page 178.

horsekeeper at Harrington Mill Pit was able by the use of the Blast lamp to descend the upcast shaft to attend to his horses while repairs were being carried out in the downcast shaft.

A subsequent modification of this lamp dispensed with the water cisterns (Figs. 4 and 5). Air was forced by a bellows into the lamp, through the oil in the oil-vessel, the level of the oil being prevented from getting so low as to uncover the opening of the pipe by resting the wick on a false bottom some little distance above the actual bottom of the oil-vessel. The

FIG. 5.—DR. CLANNY'S BLAST LAMP (SECOND FORM).

Reproduced by permission of the Royal Society of Arts from their *Transactions*, 1816, vol. xxxiv., plate vii.

outlet from the lamp was through a vertical chimney tapered to a fine point. The lamp was so arranged that it could be carried on a belt worn by a boy. The lamp was fastened on the left side, the bellows being attached to the right side of the belt, so that the boy could work the bellows with his right hand. This lamp was described, with illustrations, by Mr. J. H. H. Holmes in a

communication to the Royal Society of Arts,* dated April 14th, 1816, and the Society awarded Dr. Clanny its silver medal for the lamp in 1816.

Dr. Clanny's second lamp—the "Steam lamp" (Fig. 6)—

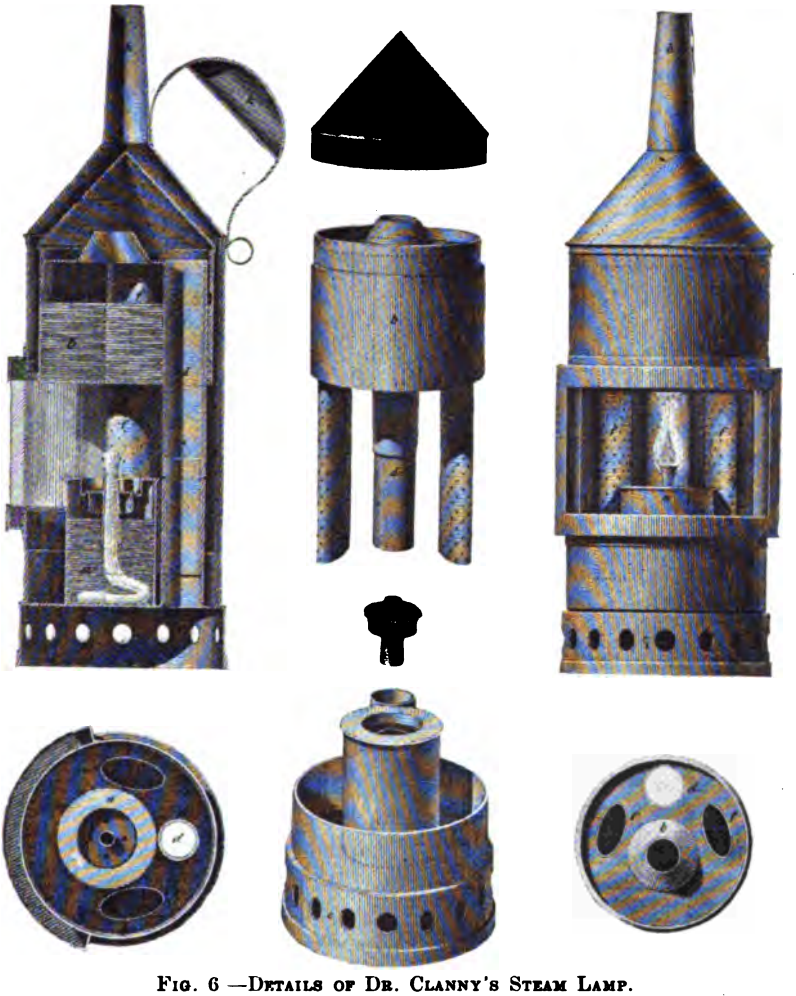

FIG. 6.—DETAILS OF DR. CLANNY'S STEAM LAMP.

Reproduced by permission of the Royal Society of Arts from their *Transactions*, 1817, vol. xxxv., plate i.

also made of tin or copper with a glass window, was constructed on a different principle. Air passed in through a tube in the bottom of the lamp, and was conducted through an extension

* *Transactions* of the Royal Society of Arts, 1816, vol. xxxiv., page 121.

of the tube to a point high up in the lamp. Above the oil-vessel and flame, and situated about the middle of the lamp, was a water reservoir, which was heated by the oil-flame, so as to generate steam by boiling the water. The air admitted through the inlet-tube was conducted below the oil-vessel by two tubes, and then passed up the sides of the cistern and out through a chimney.

The object of the steam was to neutralize the explosive character of the atmosphere in the lamp. "In the first instance the firedamp is extinguished by being diluted with steam, and soon afterwards the flame of the oil lamp dies out."*

This lamp was exhibited by Dr. Clanny in December, 1816, to the Society in Sunderland for Preventing Accidents in Coal Mines, and was the subject of a communication† submitted by him to the Royal Society of Arts on April 2nd, 1817; to this paper is attached a note to the effect that "one of the lamps is preserved in the Society's repository." The Royal Society of Arts awarded its gold medal to Dr. Clanny for this lamp in 1817. The lamp is said to have been "much used" in Harrington Mill Pit, Whitefield Pit, and Engine Pit.

A third lamp of Dr. Clanny's was the "Gas-light" lamp,‡ which is stated to have been designed to burn firedamp in lieu of oil, in an atmosphere charged with the gas. In its construction it was similar to the Steam lamp.

In 1815 Dr. Clanny was occupied in improvements to his "Bellows" lamp. He invented a "re-lighter," consisting of a match of hyper-oxy-muriate of potash§ and concentrated sulphuric acid, which he stated would light the wick in an atmosphere of inflammable air. He also made arrangements for fitting a pipe to the valves of the bellows so that air could be derived from a distance if the lamp had to be used in the presence of firedamp. In order to make his lamp more easily portable, he arranged for it to be carried "in a train or a wheel-barrow," the bellows being worked off the wheel. The cost of a Clanny lamp in copper appears to have been from 30s. to 35s.;

* The principle of this lamp was explained fully by Dr. Clanny in his evidence before the Select Committee of the House of Lords, 1849, Question No. 4,685.

† *Transactions* of the Royal Society of Arts, 1817, vol. xxxv., page 75.

‡ "Practical Observations on Safety Lamps for Coal Mines," by William Reid Clanny, M.D., Thomson's *Annals of Philosophy*, 1816, vol. viii., page 353.

§ Chlorate of potash.

in block tin, about 17s. A mechanical apparatus for working the bellows is also mentioned; this would run for two hours without being wound up, and cost 30s.*

It seems clear that Dr. Clanny considered himself to be the first inventor of a safety-lamp. He stated in his evidence before the Select Committee on Accidents in Mines (1835) that his lamp had been used in Lady Frances Vane's ("now Lord Londonderry's") mines before Sir Humphry Davy's visit to the North of England, and in later years that he "had given a safety-lamp to the public, and it had been tried in 100 acres of inflammable air, at the exploding point, before Sir Humphry Davy gave any lamp to the community."†

In 1844 he wrote to the *Mining Journal*‡ and stated his claim to priority of the invention of a safety-lamp. This letter was in reply to one written by Mr. John Murray in a previous issue of the *Mining Journal*, in which he put forward a similar claim on his own behalf. In this letter Dr. Clanny wrote that the six safety-lamps "which I have freely given to the public during a period of thirty years have been in all respects perfectly safe." Three of these lamps have been mentioned already; the others will be described later.

Dr. Clanny's claim was recognized and acknowledged by many of his contemporaries. Mr. J. H. H. Holmes, the author of *A Treatise on the Coal Mines of Durham and Northumberland*, was one of his strongest supporters, while Mr. J. J. Wilkinson, Mr. George Stephenson, and Mr. Matthias Dunn all bore testimony in his favour. Sir Humphry Davy acknowledged the assistance that he had received from him.

The Select Committee on Accidents in Mines (1835) reported that the principles of the construction of the safety-lamp "appear to have been practically known to the witnesses, Clanny and Stephenson, previously to the period when Davy brought his powerful mind to bear on the subject."

* *A Treatise on the Coal Mines of Durham and Northumberland*, by J. H. H. Holmes, 1816, page 121. Paper communicated by Dr. Clanny to the Royal Society on December 7th, 1815. This paper was not published in the *Philosophical Transactions*, but was retained in manuscript. An abstract of it is given in Thomson's *Annals of Philosophy*, May, 1816, page 368.

† *Priority of the Invention of the Safety Lamp*, by W. Reid Clanny, M.D., *Gateshead Observer* Office, 1844. See also his evidence before the Select Committee on Accidents in Mines, 1835, Question No. 341.

‡ 1844, vol. xiv., page 22.

The South Shields Committee for Investigating the Causes of Accidents in Coal Mines (1843) expressed the opinion that—

"Dr. Clanny, in this country, appears to have been the first man of science that conceived it possible to enter into a contest with this destructive element [firedamp], and, sustained by his unwearied philanthropy, has never ceased, for 30 years, to devote his talents and exertions to mitigate the horrors consequent upon its explosions. A life so spent, it is to be hoped, will not be allowed to pass without some mark of respect from his country, or of gratitude from those he has laboured so much to benefit."*

In 1846 a committee was formed to raise funds for a public testimonial to Dr. Clanny, and on February 3rd, 1848, he was presented with "a splendid silver salver" and a purse of gold at a meeting held at the Athenæum at Sunderland.† It was fortunate that this tardy recognition of the part played by Dr. Clanny in the invention of the safety-lamp was not delayed much longer, for he died on January 10th, 1850.

## VI.—GEORGE STEPHENSON.

George Stephenson was born at Wylam, near Newcastle-upon-Tyne, on June 9th, 1781; his father, Robert Stephenson, was then engaged as engineman at Wylam Pit, which belonged to Mr. Blackett. He was put to work at an early age, first under a farmer, and later on the surface at Dewley Burn Colliery; at the age of 14 he was appointed assistant fireman, thus commencing his association with engines. In 1812 he was appointed enginewright at Killingworth Colliery. His career as an engineer and in connexion with railways is well known. He died at Tapton House, near Chesterfield, on August 12th, 1848.‡

In 1815 Stephenson, who was then enginewright at Killingworth, began to turn his attention to the possibility of inventing a safety-lamp. In August of that year he "was in the habit of making experiments upon blowers," and in this way he discovered the extinctive properties of the "burnt air" (carbonic-acid gas) produced by the burning of a candle. He "found that when blowers were lighted, and a number of lighted candles, viz., four, five, or six, were held to the windward of the

* *The Report of the South Shields Committee Appointed to Investigate the Causes of Accidents in Coal Mines*, 1843, page 11.

† *A Treatise on the Winning and Working of Collieries*, by Matthias Dunn, 1848, page 179.

‡ *The Life of George Stephenson, Railway Engineer*, by Samuel Smiles, 1858.

lighted blowers, the blowers were put out 'by the burnt air which was carried towards them.'" He also noticed that when firedamp was ignited an appreciable length of time was necessary for the flame to travel from one point to another, and he thought that if a current of air could be produced in the opposite direction at a greater velocity than that at which the burning firedamp travelled, it would be possible to arrest it and to prevent the flame from passing at all. "Hence, he conceived that, if a lamp could be made to contain the burnt air above the flame, and to permit the firedamp to come in below in small quantity, to be burnt as it came in, the burnt air would prevent the passing of explosion upwards, and the velocity of the current from below would prevent its passing downwards."*

Accordingly, Stephenson's first lamp†—the "Tube and Slider" lamp—was made to take in its air through a tube situated in the centre of the wick; this tube was ½ inch in diameter, and the lower end of it was situated in the centre of the bottom of the lamp; a shutter or slide was affixed to the bottom of the lamp, and could be drawn wholly or partly over the lower end of the tube, thus admitting sufficient air to support combustion, while preventing the communication of explosion to the external atmosphere.

This lamp was tested underground at Killingworth Colliery on October 21st, 1815, by George Stephenson in the presence of Mr. Nicholas Wood, the viewer, and of Mr. John Moodie, the underviewer, in a part of the mine where a strong blower of "hydrogen" was coming off. By arranging some "deals" the place was made very foul, and Moodie was satisfied that a candle would have caused an explosion. Wood and Moodie remained at a distance till Stephenson had made his first test; subsequently Mr. Wood assisted in the experiments.*

Before the lamp was exposed to the explosive mixture, the slide of the lamp was partly shut, so far indeed that the lamp burned but feebly in good air; "when the lamp was exposed at

* *Report upon the Claims of Mr. George Stephenson Relative to the Invention of his Safety-lamp by the Committee appointed at a Meeting holden in Newcastle on the First of November, 1817.* Mr. Stephenson gave an account of the steps by which he was led to the invention of his safety-lamp in his evidence before the Select Committee on Accidents in Mines, 1835, Questions No. 1,537 and 1,544.

† The description of these lamps is taken from *A Description of the Safety Lamp Invented by George Stephenson and now in use at Killingworth Colliery*, 1817.

the blower, the flame increased, and then went out." The lamp was not satisfactory, as it was liable to go out when moved quickly, but the main object of the experiments—to regulate the size of the opening of the tube—appears to have been attained.

Further experiments seem to have been made with the lamp, and Smiles states* that it was at this time that the experiments on tubes, which were described by Stephenson in his evidence before the Select Committee on Accidents in Mines (1835), were made. If this is correct, it raises a somewhat curious question.

In the course of the experiments some explosions occurred in the apparatus used, owing to the flame getting into the receiver, "though," Mr. Stephenson stated, "we had a piece of very fine wire-gauze put at the bottom of the pipe between the receiver and the pipe through which we were forcing the current."† If Smiles's chronology is correct, the date of these experiments must have been previous to November 4th, 1815, when Stephenson's second lamp was tried in the pit, while Sir Humphry Davy's idea of introducing air into the safety-lamp through apertures closed with fine wire-gauze was not made public until November 9th, 1815, when Davy read his first paper on the safety-lamp before the Royal Society.

Smiles stated that the apparatus used in these experiments had been borrowed from the Literary and Philosophical Society of Newcastle-upon-Tyne; but there is nothing to show whether the gauze formed part of the original apparatus, or whether it was placed in it by Stephenson and Mr. Wood, who assisted him in these experiments.

Stephenson, as the result of these investigations, decided to substitute three tubes for the single air-inlet tube previously used, and sent his first lamp to be altered accordingly.

His second lamp—the "Tube" lamp—had three small openings in the bottom of the oil-vessel, through which air could

* *The Life of George Stephenson, Railway Engineer,* by Samuel Smiles, 1858, page 109.

Mr. Nicholas Wood, in his "Address on the two late Eminent Engineers, the Messrs. Stephenson, Father and Son," mentioned some experiments on firedamp and tubes in which he assisted Mr. George Stephenson; but he placed the date of these experiments before the construction of Stephenson's first lamp. An account was given in the "Address" of an accident which happened to the apparatus owing to an explosion of gas, but no mention was made of the use of wire gauze (*Transactions of the North of England Institute of Mining Engineers,* 1859-1860, vol. viii., page 43).

† *Report of the Select Committee on Accidents in Mines,* 1835, Question No. 1,544.

enter. From these openings three tubes $3\frac{1}{2}$ inches long and $\frac{3}{32}$ inch in diameter passed through the oil-vessel, the upper ends of the tubes being inclined towards the wick, so as to discharge air close to it.

The second lamp was tried underground at a blower at Killingworth Colliery on November 4th, 1815, in the presence of Nicholas Wood, John Moodie, his son John, and George Wailes. This lamp burned better than the first one, and was found "to be perfectly safe." Two lamps of this type were made, and given to the wastemen.

FIG. 7.—GEORGE STEPHENSON'S THIRD LAMP.

Stephenson now decided that a still better method of admitting air to his lamp would be through capillary tubes. He did not, however, construct a lamp on this principle, as it occurred to him "that the air would have an easier access, and the effect might be the same if I cut away the middle of the tubes; and that the flame, if it passed through the apertures at the top would not communicate the explosion to the hydrogen beyond the plate below."* He found that with very small holes the flame did not pass even through the first plate.

Accordingly in his third lamp Stephenson arranged the admission of air through circular holes in the side (not the

* *A Description of the Safety Lamp, invented by George Stephenson, and now in use in Killingworth Colliery*, London, 1817, pages 8-9.

bottom) of the oil-vessel, and then through small holes, from $\frac{3}{25}$ to $\frac{1}{22}$ of an inch in diameter, into a space between two plates, whence the air issued to the flame through another set of small holes, from $\frac{1}{12}$ to $\frac{1}{16}$ of an inch in diameter, punched in a metal ring. This form of the lamp is shown in Fig. 7, which is taken from Plate III. in the *Report upon the Claims of Mr. George Stephenson Relative to the Invention of his Safety Lamp, by a Committee appointed at a meeting holden in Newcastle on the First of November, 1817*, and is identical with Plate III. in *A Description of the Safety Lamp invented by George Stephenson and now in use in Killingworth Colliery, 1817*.

This lamp was tried underground at Killingworth Colliery on November 30th, 1815, and was exhibited before the Literary and Philosophical Society of Newcastle-upon-Tyne on December 5th, 1815.

In the *Report upon the Claims of Mr. George Stephenson*, an illustration was given (from which Fig. 8 has been taken), showing a different form of lamp. The writers are inclined to think that this was probably an earlier form of the Stephenson lamp.

Stephenson, in his evidence, published in the Report,* stated that the first lamp that he had made and tested differed from the lamp shown in Plate I. of his pamphlet in having an open top and "conical" shape, while his second lamp was simply the first lamp altered.† He also mentioned, in his pamphlet, that the original lamp of the third type had the top of the glass contracted into a "conical" form.‡ The alteration in shape of the lamps did not escape contemporary notice, for in a letter to the *Tyne Mercury* of February 11th, 1817, addressed to Stephenson, "Simple Wire Gauze" asked—

"And by what lucky chance or brilliant conception have you happened to throw away the shape of your original lamp, which was that of a wine decanter with its bottom out, for the cylindrical shaped one of that celebrated philosopher?"§

* *Report upon the Claims of Mr. George Stephenson*, etc., page 14; see also "On Safe Lamps for Coal Mines, with a Description of the one invented by Mr. Stephenson, of Killingworth Colliery" (*The Philosophical Magazine and Journal*, by Alexander Tilloch, 1815, vol. xlvi., page 458).

† *Report upon the Claims of Mr. George Stephenson*, etc., page 16.

‡ *A Description of the Safety Lamp, invented by Mr. George Stephenson*, etc., page 10.

§ *A Collection of all the Letters which have appeared in the Newcastle Papers, with other Documents relating to the Safety Lamps*, 1817, page 39; see also "Safety Lamp Controversy," *The Philosophical Magazine and Journal*, by Alexander Tilloch, 1818, vol. li., page 63.

The " philosopher " alluded to was Sir Humphry Davy. J. H. H. Holmes and Matthias Dunn, in their books on coal-mining, show the Stephenson lamp as being conical or bottle-shaped.

The writers think that the alteration in the shape of the lamp was due to a change in Stephenson's theory as to the inlet of air to the lamp. His original idea was to make the explosive mixture of gas and air enter at such a velocity that flame could not be communicated through the inlet tube or tubes. For this he required a chimney. In his evidence before the Select Committee on Accidents in Mines (1835) he said: " I knew well that the heated air from the fire drove round a smoke jack, and that caused me to know that I could have a power from it; I knew very well that a steam engine chimney was built for the purpose of causing a strong current of air through the fire." His investigations, however, showed him that tubes for the inlet of air were not necessary, as small apertures in a metal plate would prevent the passage of flame to an explosive atmosphere outside; and he appears to have abandoned his velocity theory. Another purpose served by the chimney was to constrict the outlet for the products of combustion,* and to prevent passage of flame in that direction—probably the same idea that led to the adoption of a long narrow chimney in the Clanny lamp shown in Figs. 4 and 5; but when Stephenson discovered the action of small apertures in a metal plate, he applied this principle to the outlet of the lamp as well as to the inlet. The chimney, therefore, was no longer necessary, and a glass cylinder was probably more convenient and economical than the contracted or bottle-shaped form of glass.

Stephenson also stated† that his first " trimmer " (that is, pricker) consisted of a wire down the chimney of the lamp, and that the trimmer was moved into the position shown in the illustrations after Sir Humphry Davy's lamp and trimmer appeared, and that the " safety screw " was adopted from that lamp.

* In the Report of Lord Strathmore's Committee (*Report upon the Claims of Mr. George Stephenson*, etc., page 7) the use of an open-topped chimney in the Stephenson lamp is noticed :—" It may possibly, however, be observed that the chimneys of Mr. Stephenson's Lamp were not furnished with a system of safety apertures for carrying off the foul air." The Committee proceeded to explain that the reason was that Stephenson's observations had taught him that this was not absolutely necessary, and they justified the practice by a quotation from Sir Humphry Davy's writings (*Philosophical Transactions* of the Royal Society, 1816, part i., page 13).

† *Report upon the Claims of Mr. George Stephenson*, etc., page 16.

In November, 1817, a committee, of which the Earl of Strathmore was Chairman, and Mr. R. W. Brandling was Secretary, issued an appeal for a public testimonial to George Stephenson, by which about £1,000 was raised. Part of this money was devoted to the purchase of a silver tankard, which, with the remainder of the money subscribed, was presented to Stephenson at a public dinner given in the Assembly Rooms at Newcastle-upon-Tyne on January 12th, 1818, Mr. Charles John Brandling being in the chair.*

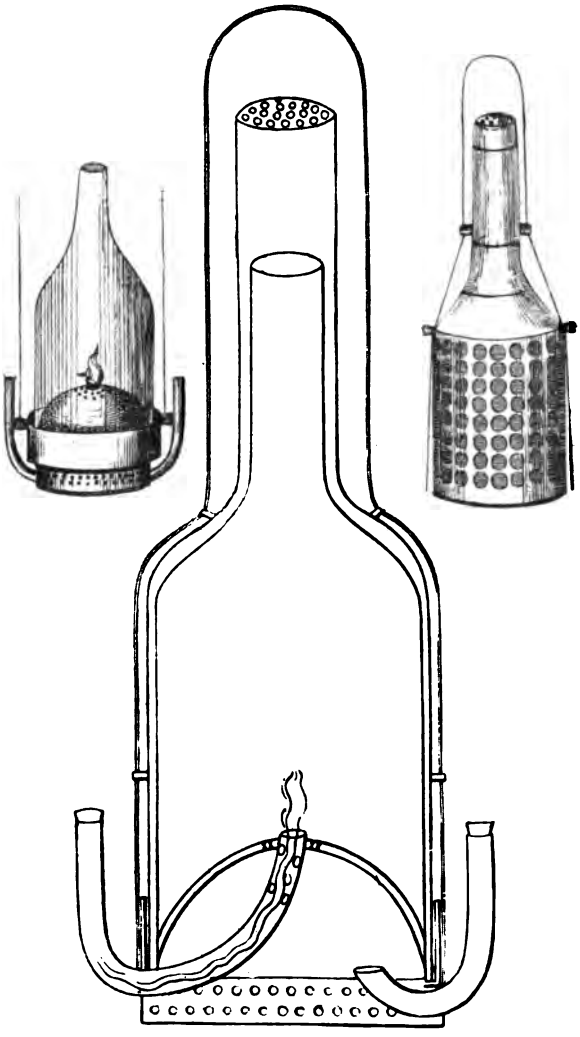

FIG. 8.—EARLY FORM OF STEPHENSON LAMP.

The colliers also presented Stephenson with a silver watch.†

The lamp shown in Fig. 7 was not, however, the final form of the Stephenson lamp. After Sir Humphry Davy's discovery of the properties of the wire-gauze cylinder, this material, of

* *The Life of George Stephenson, Railway Engineer*, by Samuel Smiles, 1858, page 129.

† *The Life of George Stephenson and his Son Robert Stephenson*, by Samuel Smiles, 1868, page 125.

iron and of the standard size, was substituted in the Stephenson lamp for the punched plate which surrounded the glass (Figs. 9 and 10). The wire-gauze cylinder was about 5½ inches in height and 2¼ inches in diameter, the glass cylinder fitting tightly inside it. Air for combustion entered the lamp through small holes perforated either horizontally through the ring to which

FIG. 9.—STEPHENSON LAMP. FIG. 10.—STEPHENSON LAMP.

Figs 9 and 10 are reproduced from a lamp in the possession of the University of Sheffield.

the standards were attached at their lower ends, or vertically through a flange just above this ring—the latter arrangement being made to prevent the holes from becoming clogged with fine dust. Stephenson was, therefore, the first to adopt the under air-feed type of lamp.

The writers have been unable to discover at what date wire-gauze was substituted for punched plate in this lamp. The

South Shields Committee in their Report of 1843 described the lamp as being surrounded by a wire-gauze cylinder, and gave the weight of the lamp as 2 pounds 6 ounces. The Stephenson lamps tested by the British Royal Commission on Accidents in Mines (1886) all had their inlet-holes also protected with wire-gauze, so that ultimately this lamp was greatly indebted to Sir Humphry Davy for his discovery.

The Stephenson lamp never seems to have been as widely used as the Davy, but the South Shields Committee preferred it, because, owing to its glass, it prevented the action of a lateral current in passing flame. In currents of explosive mixture passing at a low velocity, the flame of the lamp was generally extinguished without igniting the gas inside the lamp.* The British Royal Commission of 1886,† however, found that in currents of higher velocity a down draught was set up in one portion of the glass cylinder, causing passage of flame. They considered that Stephenson lamps became untrustworthy in currents having velocities ranging from 800 to 1,000 feet per minute, and that at the higher velocity they almost always caused an explosion.

The South Shields Committee of 1843 stated that, when the glass was broken, the capacity of the gauze cylinder was too large to be safe in explosive mixtures, the internal diameter being 2¼ inches against 1½ inches in the Davy. The Royal Commission of 1886 reported that "if the glass breaks, the lamp at once becomes a Davy lamp."

## VII.—Sir Humphry Davy.

Humphry Davy was born on December 17th, 1778, near Penzance, and was educated at Penzance Grammar School and at Truro. He was apprenticed to Mr. John B. Borlase, a surgeon and apothecary in Penzance, and devoted his attention especially to chemistry. In 1798 he became Superintendent in the laboratory of the Pneumatic Institution at Bristol belonging to Dr. Beddoes, where he was employed in investigating the

* The British Royal Commission (Final Report, 1886, page 76) stated that "when the supply of air from below is sufficient to support the flame, and an explosive mixture comes upon the lamp, if the gas becomes ignited at all, it will only burn at the bottom of the lamp. The small quantity of gas thus ignited being insufficient to heat the gauze to a temperature high enough to cause an explosion, it may continue to burn harmlessly for any length of time, provided the glass is not broken by the heat applied to its lower edge."

† *Final Report of the Royal Commission on Accidents in Mines*, 1886.

medicinal properties of various gases—among them carburetted hydrogen. On February 16th, 1801, he was appointed Assistant Lecturer in Chemistry, Director of the Laboratory, and Assistant Editor of the Journals of the Institution, at the Royal Institution of Great Britain, and on May 31st, 1802, was appointed Professor. In 1803 he was elected a Fellow of the Royal Society, and was Secretary of that Society from 1807 to 1812. In 1811 he was made an Honorary LL.D. of Trinity College, Dublin. On April 8th, 1812, he was knighted. He resigned his professorship at the Royal Institution on April 5th, 1813, but was elected Honorary Professor of Chemistry. On October 20th, 1818, he was created a baronet, and was elected President of the Royal Society on November 30th, 1820. In addition to his scientific studies, Davy was fond of fishing, shooting, and travelling. He died at Geneva on May 29th, 1829.*

Mention has already been made of the decision of the Society in Sunderland for Preventing Accidents in Coal Mines to approach Sir Humphry Davy as to the best means of overcoming danger from firedamp. In pursuance of this resolution, Mr. J. J. Wilkinson† called at the Royal Institution in order to see Sir Humphry Davy, but was unable to do so, as Sir Humphry had gone to Paris. Mr. Wilkinson wrote to him, but, as he had neglected to pay foreign postage, his letter was returned to Mr. W. Burn, the Secretary of the Society. The matter remained in abeyance till the summer of 1815, when Dr. Gray, as Chairman of the Committee, was asked to write to Sir Humphry Davy. Sir Humphry was then "on a shooting excursion" in Scotland, and his reply was dated from "Lord Somerville's, near Melrose, N.B., August 3rd, 1815."‡ He accepted the invitation, and on his way south he stopped at Newcastle-upon-Tyne, and met several of the committee and others at Dr. Gray's. In his account§ of this visit he offered his special thanks to the Rev.

* *The Life of Sir Humphry Davy, Bart., LL.D.*, by John Ayrton Paris, M.D., F.R.S.; *The Collected Works of Sir Humphry Davy, Bart., LL.D., F.R.S.*, edited by his brother, John Davy, M.D., F.R.S., vol. i., *Memoirs of his Life*. The writers are indebted to the Secretary of the Royal Institution of Great Britain for some of the foregoing information.

† *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 285.

‡ *The Collected Works of Sir Humphry Davy, Bart., LL.D., F.R.S.*, edited by his brother, Dr. John Davy, M.D., F.R.S., vol. i., page 200; and *The Life of Sir Humphry Davy, Bart., LL.D.*, by John Ayrton Paris, M.D., F.R.S., 1831, vol. ii., page 78.

§ *Philosophical Transactions* of the Royal Society, 1816, page 1.

Dr. Gray, Mr. Cuthbert Ellison, M.P., the Rev. John Hodgson, Mr. John Buddle, and Mr. Matthias Dunn; he mentioned that Dr. Fenwick, Dr. Clanny, and Mr. Fenwick had offered him their assistance, and that he had read Mr. Buddle's report or letter to the Sunderland Society; also that the Rev. John Hodgson had informed him that if coal fresh from the mine were pounded in a cask furnished with a small aperture, the gas from the aperture was inflammable. Davy proved this by breaking some coal under water, when inflammable gas was given off.

On August 24th, 1815, he visited Mr. John Buddle, and learned from him the conditions under which coal was then being worked: just before parting he said to Mr. Buddle "I think I can do something for you."*

On August 25th, 1815, Davy visited the collieries of Hebburn and Wallsend. Later on, after his return to London, he acknowledged the receipt of six specimens of firedamp in bottles, collected by Matthias Dunn from a blower at Hebburn Colliery.

A letter of Buddle's,† dated August 24th, 1815, intimated that at first Davy entertained the idea of neutralizing firedamp by generating some gas, but that his main object was the production of a light which should be safe in explosive mixtures of firedamp and air. He tried phosphorus and "electric light" in close vessels, but without satisfactory results. He then turned his attention to lamps, and produced the following:—

"The Safe lamp, in which a candle or lamp burns in a safe lantern which is airtight in the sides, and has tubes below for admitting air, a chamber above, and a chimney for the foul air to pass through."

The "Blowing" lamp, into which air was forced by a small pair of bellows.

The "Piston" lamp, in which a candle was made to burn in a small glass lantern furnished with a piston.

The "Charcoal" lamp, a small iron cage on a stand containing very small pieces of very well burnt charcoal blown up to a red heat.

The "Fire-valve Lantern," in which the admission of air to the lamp was governed by a thermometrical spring at the top of

* *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 2,226.

† *The Life of Sir Humphry Davy, Bart., LL.D.*, by John Ayrton Paris, M.D., F.R.S., 1831, vol. ii., page 80.

the lamp, which closed when firedamp burned in the lamp. He did not, however, "pursue this invention" after his investigations into the nature of firedamp.*

In the meantime, Davy did not omit to inform his friends in the North of England as to the progress he was making, but wrote both to Dr. Gray and to the Rev. John Hodgson. One of these letters,† dated either the 30th or 31st of October, was read by Hodgson at "a large meeting of gentlemen interested in the coal trade of the Rivers Tyne and Wear," held on November 10th, 1815. The letter, however, was intended to be private, and its publication was perhaps unfortunate, as it figured subsequently in the Stephenson-Davy controversy; an immediate result of its being read was to bring to Hodgson's notice the fact that Stephenson was engaged in the production of a safety-lamp.

On November 9th, 1815, Sir Humphry Davy read a paper before the Royal Society "On the fire-damp of coal mines, and on methods of lighting the mines so as to prevent its explosion,"‡ in which he gave an account of the results of his investigations up to that time.

He had ascertained the conditions under which firedamp explodes, the degree of its inflammability, and its behaviour when mixed with certain quantities of air. He found that firedamp was—

> "much less combustible than other inflammable gases. It was not exploded or fired by red hot charcoal or red hot iron; it required iron to be white hot, and itself in brilliant combustion, for its inflammation. The heat produced by it in combustion was likewise much less than that of most other inflammable gases, and hence, in its explosion, there was much less comparative expansion."§

He found also that the addition of carbonic-acid gas or of "azote" (nitrogen) to an explosive mixture of firedamp and air diminished its explosibility.

* These particulars are taken from *The Life of Sir Humphry Davy, Bart., LL.D.*, by John Ayrton Paris, M.D., F.R.S., 1831, vol. ii., page 84.

† Letter of the Rev. John Hodgson to the *Newcastle Courant*, January 28th, 1817. *A Collection of all the Letters which have appeared in the Newcastle Papers, with other Documents Relating to the Safety Lamps*, 1817, page 32; *The Life of George Stephenson, Railway Engineer*, by Samuel Smiles, 1858, page 116; *The Life of Sir Humphry Davy, Bart., LL.D.*, by John Ayrton Paris, M.D., F.R.S., 1831, vol. ii., pages 81-86.

‡ *Philosophical Transactions* of the Royal Society, 1816, page 1.

§ *On the Safety Lamp for Coal Miners*, etc., by Sir Humphry Davy, 1818, page 10.

Davy had studied also the passage of flame through tubes of glass and of metal filled with explosive mixture, and found that in a tube ¼ inch in diameter and 1 foot long more than a second was required for the flame to pass from one end of the tube to the other, while he could not make any mixture explode in a glass tube ¼ inch in diameter; the gas used in these experiments was in his opinion "more inflammable than firedamp," as it "consisted of carburetted hydrogen gas mixed with some olefiant gas." He also discovered that metallic tubes were more effective than glass tubes in preventing explosions, and that—

"A mixture of the gas with air would not explode in metallic canals or troughs, when their diameter was less than ¼ of an inch, and their depth considerable in proportion to their diameter; nor could explosions be made to pass through such canals"; also that "explosions would not pass through very fine wire sieves or wire gauzes."

The conclusions which Davy drew from the facts that he had ascertained were clearly stated by him in a later publication in 1818, entitled *On the Safety Lamp for Coal Miners*, as follows:—

"In reasoning upon these various phenomena it occurred to me, as a *considerable* heat was required for the inflammation of the fire-damp, and as it produced in burning comparatively *a small degree* of heat, that the effect of carbonic acid and azote, and of the surfaces of small tubes in preventing its explosion, depended upon their cooling powers; upon their lowering the temperature of the exploding mixture so much that it was no longer sufficient for its continuous inflammation."*

Accordingly in his paper of November 9th, 1815, he stated:—

"It is evident that to prevent explosions in coal mines it is only necessary to use air-tight lanterns, supplied with air from tubes or canals of small diameter, or from apertures covered with wire gauze placed below the flame through which explosions cannot be communicated, and having a chimney at the upper part, on a similar system for carrying off the foul air; and common lanterns may be easily adapted to the purpose, by being made air-tight in the door and sides, by being furnished with the chimney, and the system of safety apertures below and above."

Three lamps constructed on these principles were described in the paper. All of them appear to have been made of tin-plate, the light shining through four glass plates at the sides. In the first, air entered below the flame through a number of metallic tubes ⅛ inch in diameter and 1½ inches long; the products of combustion passed out through a chimney composed of two open cones guarded by a plate containing "many small apertures."

* Page 11.

In the second lamp (Figs. 11 and 12) both the inlet and outlet of the lamp were guarded by "safety canals" instead of tubes. These were "close concentric hollow metallic cylinders of different diameters, and placed so as to form circular canals of the diameter of from one twenty-fifth to one-fortieth of an inch, and an inch and seven-tenths long, by which air is admitted in much larger quantities than by small tubes."

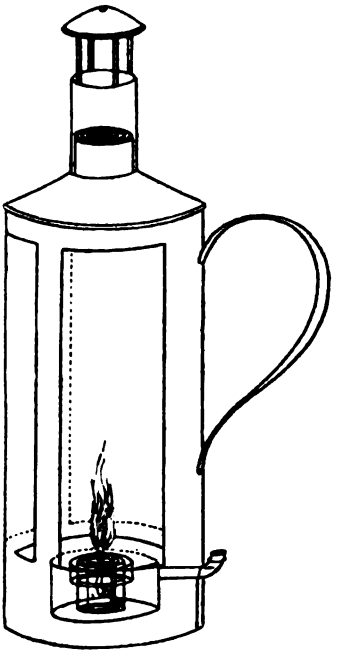

FIG. 11.—SIR HUMPHRY DAVY'S SECOND LAMP.

In his third lamp (Figs. 13 and 14) Davy arranged for the entrance of air and exit of the products of combustion "through apertures covered with brass wire gauze of $\frac{1}{200}$ of an inch in thickness, the apertures of which should not be more than $\frac{1}{120}$ of an inch; this stops explosions as well as long tubes or canals, and yet admits of a free draught of air."

The paper concluded with further particulars of experiments on tubes and metallic gauze, and with some remarks on the physiological aspect of firedamp.

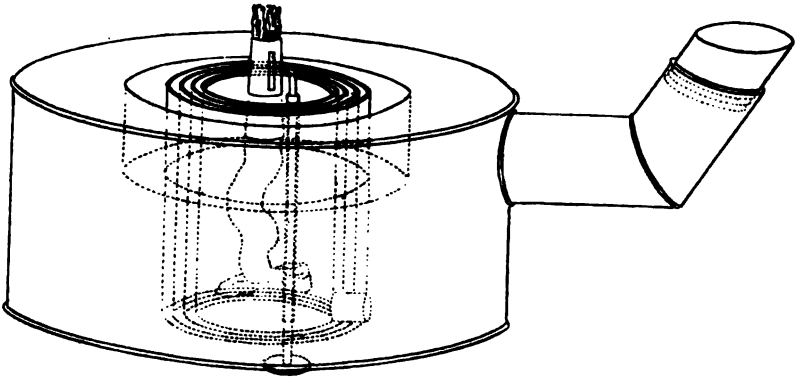

FIG. 12.—SIR HUMPHRY DAVY'S SECOND LAMP: ENLARGED VIEW OF THE CONCENTRIC CYLINDERS FOR THE ADMISSION OF AIR.

Figs. 11 and 12 are reproduced by permission of the Royal Society from the *Philosophical Transactions*, 1816, figs. 1 and 2, plate i., page 22.

By November 9th, 1815, Davy had, therefore, discovered the principles on which his safety-lamp was to be constructed; but he had not yet conceived the idea of surrounding the flame of the lamp with a cylinder of wire-gauze. A little more than a month seems to have elapsed before this idea occurred to him.

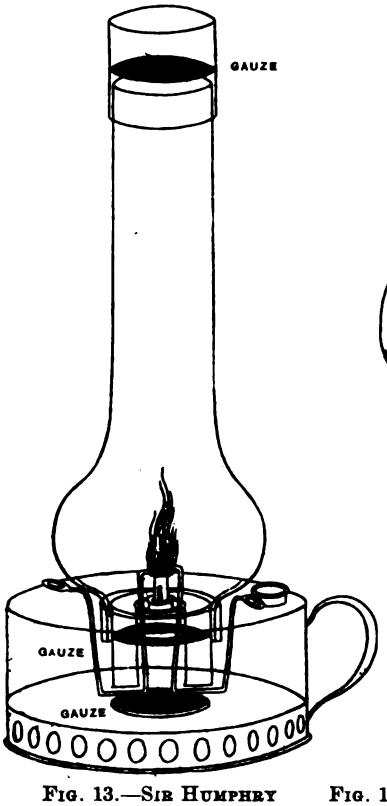


FIG. 13.—SIR HUMPHRY DAVY'S THIRD LAMP.

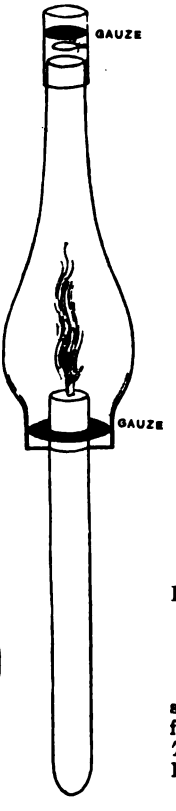


FIG. 14.—SIR HUMPHRY DAVY'S THIRD LAMP.

FIG. 15.—EXPERIMENTAL MODEL OF SIR HUMPHRY DAVY'S WIRE-GAUZE SAFETY-LAMP.

Reproduced by permission of the Royal Society from the *Philosophical Transactions*, 1816, fig. 11, plate i., page 22.

Figs. 13 and 14 are reproduced by permission of the Royal Society from the *Philosophical Transactions*, 1816, figs. 9 and 10, plate i., page 22.

On January 1st, 1816, Sir Humphry Davy* wrote to Dr. Gray, informing him that he had made a very important discovery, which was evidently the application of the wire-gauze cylinder. He anticipated that lamps and candles protected by

* *The Life of Sir Humphry Davy, Bart., LL.D.*, by John Ayrton Paris, M.D., F.R.S., 1831, vol. ii., page 96.

this would be "absolutely safe," and that the method would be economical. He attributed this discovery to his experiments on wire sieves.

The discovery of the properties of the wire-gauze cylinder was communicated by Davy to the Royal Society in a paper on January 11th, 1816, entitled "An account of an invention for giving light in explosive mixtures of fire damp in coal mines by consuming the fire damp." In this paper he stated that—

"This invention consists in covering or surrounding the flame of a lamp or candle by a wire sieve; the coarsest that I have tried with perfect safety contained 625 apertures in a square inch, and the wire was $\frac{1}{76}$ of an inch in thickness, the finest 6,400 apertures in a square inch, and the wire was $\frac{1}{254}$ of an inch in thickness."*

The experimental lamp used by Davy was shown in Fig. 11 on the plate accompanying his paper of November 9th, 1815, and Fig. 15 is reproduced from it. The Royal Society possesses a very early experimental model of the lamp.

The first Davy safety-lamps appear to have been finished about the end of 1815 or early in 1816. Matthias Dunn† claims to have had the honour of trying the first of Sir Humphry Davy's lamps in some of the most inflammable parts of Hebburn Colliery on January 1st, 1816. But on that day Davy wrote to Dr. Gray saying that he hoped to send models of his lamps and a printed account of his results "on Wednesday." Mr. Buddle stated‡ that Sir Humphrey sent him two Davy lamps, with some instructions, and that he tried them in an explosive mixture on the surface before taking them underground, but he gave no dates.

The Rev. John Hodgson and Matthias Dunn (the resident viewer at Hebburn Colliery) carried out some experiments with the Davy lamps at that colliery on January 9th, 1816, in which Mr. Seymour (the underviewer) and "some of the workmen" took part. The tests were most satisfactory, and were repeated by Hodgson, Buddle, and Dunn at the same colliery on January 17th, when equally good results were obtained. On the latter occasion the lamps were tested in explosive atmospheres of greater extent: in one place a miner was working by the light

* *Philosophical Transactions* of the Royal Society, 1816, page 23.

† *A Treatise on the Winning and Working of Collieries*, by Matthias Dunn, 1852, page 166.

‡ *Report of the Select Committee on Accidents in Mines*, 1835, Question No. 2,226.

of a flint-and-steel mill, and was greatly alarmed at the approach of a Davy lamp, which he took to be a candle.

Mr. Buddle has put on record his feelings on this occasion, as follows:—

"to my astonishment and delight, it is impossible for me to express my feelings at the time when I first suspended the lamp in the mine, and saw it red hot; if it had been a monster destroyed, I could not have felt more exultation than I did. I said to those around me, 'We have at last subdued this monster.'"*

FIG. 16.—THE FIRST DAVY SAFETY-LAMPS THAT WERE TAKEN UNDERGROUND.
These lamps are now in the Science Museum, South Kensington.

The lamp carried by the Reverend John Hodgson and another lamp used also on January 9th and 17th, 1816—"the first that were ever used in a coal mine"—were presented by Hodgson "to Miss Emma Trevelyan of Wallington (Mrs. Wyndham), who gave them to her brother, Mr. Arthur Trevelyan," by whom they were "placed in the Museum of Practical Geology in London."†

These lamps are now in the collection of safety-lamps in the Science Museum at South Kensington, and Fig. 16 has been reproduced from a photograph of them by permission of the authorities of the Science Museum.

* *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 2,226.

† Most of these particulars are derived from *A Memoir of the Rev. John Hodgson, M.A., Vicar of Hartburn*, by the Rev. James Raine, M.A., vol. i., pages 178-183.

Davy's experiments on wire-gauze led him to prefer, for fire-damp, one of iron wire, composed of wires of from a fortieth to a sixtieth of an inch in diameter, and containing twenty-eight wires to the inch, or 784 apertures to the square inch. He pointed out, however, that, in proportion to the inflammability of the gas, the apertures in the gauze should be made smaller, and the radiating surfaces greater, and that "reduplications of wire gauze," that is, several gauzes superposed (Fig. 17), might be necessary for continuous currents of explosive mixture. He

FIG. 17.—DAVY LAMP WITH TWO GAUZES.

recommended that the gauze should not be made of or covered with any easily combustible metal, for which reason brass wire or tinned-iron wire should not be used. No aperture should be allowed to exist in the body of the lamp. As the air-current naturally entered the gauze near the flame, and the products of combustion rose upwards, the top of the gauze cylinder was most liable to be strongly heated: as a precaution, a short cap of gauze was placed over the top of the main gauze cylinder.

In addition to double-gauze lamps, Davy brought out lamps with twilled gauze, and with gauzes with several seams. He

tried several different forms of lamp and various kinds of construction. The Royal Institution of Great Britain possesses a very interesting collection of early forms of the Davy lamp.

The proportion between the cubic contents of a safety-lamp and the area of conducting surface of gauze also claimed Davy's attention, as it has that of subsequent investigators. He considered that—

"the most convenient size for a common working-lamp is from eight to ten inches in height, and two to two-and-a-half in breadth. If the wire cylinders are larger, there is too much heat produced in them by the combustion of explosive mixtures."*

While the top of a slender cylinder of wire gauze hardly ever became dull red in an explosive mixture, in a larger cylinder of the same material the central part of the top soon became "bright red."

Davy also experimented with lamps in which "surfaces of glass were used without a guard of wire gauze," but he regarded them as "highly dangerous," although he suggested that plates of mica might be used instead. He tried admission of air below the flame through wire-gauze, the current of air through the lamp being "determined" by wire-gauze cylinders above "on the plan of Argand's." He found the light brilliant, but the heat produced was so great as "to boil the oil in the reservoir." He evidently did not approve of the principle of feeding the safety-lamp with air from below the flame through tubes or holes in thick metallic plates, as he considered that lamps so constructed were liable to become so hot as to enable the combustion of the explosive mixture to be communicated to the atmosphere outside—"for explosion will be communicated by any aperture, however small, provided it be sufficiently heated."

In the course of his experiments Davy discovered that platinum and palladium, when heated in the presence of oxygen and firedamp, would induce combustion of the firedamp and become red hot, and the degree of brightness of the glowing wire was dependent on the quantity of firedamp present. He, therefore, arranged a cage or spiral coil of platinum around the flame of his safety-lamp to give light to the miner when the oil-flame of the lamp was extinguished in firedamp, to indicate the quantity of firedamp present, and to act as a re-lighter when the lamp was

* *On the Safety Lamp for Coal Miners*, etc., by Sir Humphry Davy, 1818, page 143.

removed into an atmosphere containing a sufficiency of oxygen. This invention does not appear to have been extensively used.

Despite all that was said in later years to the contrary, Sir Humphry Davy was fully aware that his safety-lamp might be unsafe in explosive currents unless they moved at very low velocities. To obviate this source of danger, he recommended the use of twilled gauze, in which the radiating surface was greater than that of ordinary gauze, while the circulation of air was less, so that with it an equal temperature would be preserved: he also suggested the introduction of a glass cylinder inside the wire-gauze cylinder, above the flame, or of a semi-cylinder of glass or mica. But the device on which he appears to have placed most reliance was a tin screen "which slides upon the frame wires of the lamp, and encircles the circumference of the gauze cylinder to an extent of about one-half to two-thirds of its circumference."*

On September 6th, 1816, when Sir Humphry Davy visited the workings of the G Pit at Wallsend Colliery in company with Buddle to see the behaviour of his lamp in the presence of firedamp underground, he took the opportunity to explain to Buddle, to the viewer, overmen, "and others" this source of danger, and during the same visit he was present at experiments conducted at the Morton West Pit of Mr. J. G. Lambton (afterwards Earl of Durham) for the same purpose. At this colliery a blower of gas had been piped to the surface, and the tests were made on this gas; the single-gauze lamp, lamps fitted with a tin shield, and double-gauze lamps, were exposed to the gas.

"The single gauze lamp did not communicate explosion, as long as it was red hot and slowly moved through the currents; but when it was fixed at the point of most intense combustion, it reached a welding heat, the iron wire began to burn with sparks, and the explosion then passed."†

Buddle complained that the flame of the ignited firedamp in one experiment burned the nap off his coat. The shielded lamps and double-gauze lamps appear to have resisted the passage of flame. Sir Humphry Davy pointed out the lesson to be learned from these experiments:—

"Now, gentlemen, you see the nature of the danger to which you are exposed in using the lamp, and I caution you to guard against it, in the manner I have shown you. This is to show the only case in which the lamp

* *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Mr. John Buddle's evidence, Question No. 2,227.

† *On the Safety Lamp for Coal Miners*, etc., by Sir Humphry Davy, 1818, page 38.

will explode, and I caution you and warn you not to use it in any such case when you can avoid it, without using the shield."*

Davy also suggested that a workman carrying a single-gauze lamp in an explosive atmosphere near a blower, with the temperature of his lamp rapidly increasing, might lessen the heat by shielding the lamp with his body or with his clothes.

Davy further experimented on the action of coal-dust thrown on to a lamp in which firedamp was burning, because the colliers

FIG. 18.—DAVY SAFETY-LAMP.

FIG. 19.—DAVY SAFETY-LAMP.

were alarmed at the flashes produced under these conditions; but he was of opinion that explosion could not be produced in this way.†

The Davy safety-lamp (Figs. 18 and 19) consisted of a circular oil-vessel with a round wick, and a pricker passing through a

* *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 2,227

† *On the Safety Lamp for Coal Miners*, etc., by Sir Humphry Davy, 1818, page 140.

tube in the oil-vessel. In the earlier patterns the oil-tube was situated outside the gauze, closed by a cap (Figs. 16 and 17); later on the oil-tube was moved inside the gauze, in order to avoid a possible source of danger. The oil-vessel was surmounted by a cylinder of gauze, 6 inches long and 1½ inches in diameter, with a short cap of gauze placed over the top of the main gauze cylinder. Above the gauze was a circular guard, connected to the ring which screwed on to the oil-vessel by four standards. A screw-lock was used to prevent the lamp from being opened. The lamp weighed 1 pound 6 ounces.

When the Davy lamp is exposed to a mixture of firedamp and air, the mixture burns in the lamp, and in a current of explosive mixture the flame may pass through the gauze if the speed of the current exceeds a certain limit. As has been shown, this was known to the inventor, and it has been proved repeatedly by subsequent investigators. The British Royal Commission on Accidents in Mines (1886) stated that "in an explosive current with the very moderate velocity of 400 feet per minute, the ordinary Davy lamp ceases to afford protection for more than a few seconds, unless the diameter of the gauze is very small."

In order to overcome this difficulty, various forms of protected Davy, and Davy lamps enclosed in a case, were introduced in later years: the Royal Commission of 1886 found that the safety of the lamp was greatly increased by the addition of a properly-designed case.

At meetings of the coal-owners held at Newcastle-upon-Tyne on August 31st, 1816, and on October 11th, 1816, it was decided to open a subscription-list for a testimonial to Sir Humphry Davy. The amount obtained is stated by some authorities to have been £2,500, by others £2,000. This sum of money was expended in the purchase of a service of plate, which was presented to Sir Humphry at a banquet given at the "Queen's Head," Newcastle, Mr. J. G. Lambton (afterwards Earl of Durham) being in the chair. The date of this banquet is stated by Sir Humphry to have been October 11th, 1817, and in this he is supported by Mr. R. L. Galloway and Dr. J. Davy. Dr. Paris and Mr. J. Holland, however, stated that the banquet was arranged for September 25th, 1817.

In 1825 the Emperor Alexander of Russia presented to Sir Humphry Davy a superb silver-gilt vase, standing on a circular

tray enriched with medallions. On the cover was a figure about 16 or 18 inches high representing the God of Fire weeping over his extinguished torch. The whole was worth about 180 guineas.*

In addition to the vote of thanks of the coal-trade of the North of England,† Sir Humphry Davy received a vote of thanks from the united colliers of Whitehaven, from the Grand Jury of Durham, and from the Chamber of Commerce of Mons.

It is interesting to notice that none of the three inventors of the earliest safety-lamps covered their inventions by patents. Buddle records that in the autumn of 1816, when Sir Humphry Davy was visiting some of the collieries in the North of England, he spoke to him on the subject. Davy's reply was: "No, my good friend, I never thought of such a thing; my sole object was to serve the cause of humanity, and if I have succeeded, I am amply rewarded in the gratifying reflection of having done so."‡ It may be presumed that Clanny and Stephenson were actuated by similar motives.

## VIII.—The Controversy as to Priority of the Invention of the Safety-lamp; and other Early Forms of Safety-lamp.

The very regrettable controversy between the supporters of Stephenson and of Davy, as to which of them was to be regarded as the first inventor of the safety-lamp, appears to have originated as early as the end of 1815, but came into prominence over the question of a testimonial.

At a meeting of coal-owners held at Newcastle-upon-Tyne on August 31st, 1816, a resolution was brought forward that a present of plate, for which 500 guineas were to be raised, should be made to Sir Humphry Davy "for the invention of his safety-lamp." No objection was raised, but Stephenson stated that when the resolution was brought up at a subsequent meeting, apparently on October 11th, 1816, the wording was altered to "*his* invention of *the* safety-lamp."§ Mr. Robert William

* *The Life of Sir Humphry Davy, Bart., LL.D.*, by John Ayrton Paris, M.D., F.R.S., 1831, vol. ii., page 138.

† On March 18th, 1816, *ibid.*, page 110.

‡ *Ibid.*, page 133.

§ *A Description of the Safety Lamp, Invented by George Stephenson*, etc., 1817, page 15; see also *The Life of George Stephenson, Railway Engineer*, by Samuel Smiles, 1858, page 122.

Brandling then moved that the resolution should be postponed until " it shall be ascertained whether the merit of the invention of the safety-lamp is due to Sir Humphry Davy or George Stephenson." This motion was defeated, and, Mr. Brandling having withdrawn, it was decided to proceed with the testimonial to Sir Humphry Davy.

After this the matter remained in abeyance till November 1st, 1817, when a meeting was held in the Assembly Rooms (presumably at Newcastle-upon-Tyne), Mr. C. J. Brandling being in the chair, " for the purpose of remunerating Mr. George Stephenson for the valuable service he has rendered to mankind by the Invention of his Safety-lamp, which is calculated for the Preservation of Human Life in situations formerly of the greatest danger." The following resolutions were passed:—

" That it is the opinion of this meeting, that Mr. George Stephenson, having discovered the fact that Explosion of Hydrogen Gas will not pass through Tubes and Apertures of small dimensions, and having been the first to apply that principle in the construction of a Safety Lamp, is entitled to a Public Reward.

" That a Subscription be immediately entered into for this purpose.

" That a Committee be appointed to carry the object of this meeting into effect."*

A committee of fourteen was formed, the Earl of Strathmore being chairman, Mr. Richard Lambert treasurer, and Mr. R. W. Brandling secretary. The committee issued a "Report upon the claims of Mr. George Stephenson, relative to the Invention of his Safety-Lamp " in 1817, in which much information was given concerning the steps by which the Stephenson lamp was evolved, and comparative dates of the discoveries made by Stephenson and Davy. The committee reported that Mr. Stephenson's lamp was " justly entitled to the name of a 'Safety-Lamp,' " and drew attention to " the priority of the construction of his lamp in point of time."

Sir Humphry Davy's supporters retaliated by calling a meeting in the Assembly Rooms at Newcastle-upon-Tyne on November 26th, 1817, Mr. J. G. Lambton, M.P., being in the chair, at which the following resolution among others was passed:—" That the merit of having discovered the fact, that explosions of firedamp will not pass through tubes and apertures of small dimensions and of having applied that principle to the

* *Report upon the Claims of Mr. George Stephenson*, etc., 1817, page iii.

construction of a Safety-Lamp, belongs to Sir Humphry Davy alone." A somewhat similar statement, signed by Sir Joseph Banks, F.R.S., W. T. Brande, C. Hatchett, and W. H. Wollaston, was issued on November 20th, 1817.

Into the details of the controversy it is unnecessary to go. Those who are curious in such matters will find an excellent account of it in the first series of *The Annals of Coal Mining*, by Mr. R. L. Galloway; while Smiles (Stephenson's biographer), and Dr. Paris and Dr. Davy (Sir Humphry Davy's biographers), have dealt with it from the point of view of those who were personally interested.*

As to the relative merits of the two inventors, Stephenson deserves great credit for his work. Unacquainted with the principles of chemistry, and devoid of proper apparatus for experimenting, he was yet able to produce a lamp which seems to have been safe under the conditions for which it was designed. But to Sir Humphry Davy's work the mining community is indebted for the safety-lamp as it exists at the present day: not only did he invent a lamp which was, within limits, safe, but he laid down the principles of safety which have been followed and confirmed by subsequent investigators.

In 1814 M. Chèvremont, "Ingénieur des Mines dans le Royaume des Pays-Bas," invented and constructed a safety-lamp consisting of a cylinder of glass containing a lamp, surmounted by a small conical chimney of tin-plate, the opening at the top of which was only 1½ centimetres (0·6 inch) in diameter, to allow of the escape of the products of combustion. To the bottom of the glass cylinder was fitted a tube or pipe of leather or "*toile imperméable*," strengthened inside by a spiral iron wire, which connected the lamp with some source from which air free from admixture of firedamp could be obtained.†

In June, 1815. *Mr. John Murray*, Lecturer on Chemistry at Hull, published a book entitled *The Elements of Chemical Science*, in which he described a safety-lamp invented by himself. This lamp appears to have been similar to M. Chèvremont's, and like it derived its air through a tube; the outlet was through small openings in the top of the lamp.

* See also *The Philosophical Magazine and Journal*, by Alexander Tilloch, 1818, vol. li., page 63.

† *Annales des Mines*, 1823, series 1, vol. viii., page 209.

A lamp on a similar principle, invented by *Dr. John Murray* in November, 1815, is shown in Fig. 20.

In 1815 or 1816 *Mr. R. W. Brandling* brought out a safety-lamp (shown in Fig. 21), which also was supplied with air through a pipe or tube from a source uncontaminated by firedamp. This lamp was made of tin, 12 inches high by 8 inches square, with a bellows chambers at the top for accelerating the draught. It had a glass window, through which the light inside the lamp shone.

FIG. 20.—DR. JOHN MURRAY'S LAMP.

In 1815 *Mr. E. Carter*, of Exeter, wrote* to Sir Humphry Davy suggesting the use of fixed gas-lamps in collieries, the lamps to be supplied with gas and air through pipes, and the products of combustion to escape through an outlet submerged in water.

## IX.—PERIOD 1816 TO 1835.

The Davy and Stephenson safety-lamps came into use in Great Britain shortly after their invention, the Davy being the one most generally employed. Writing in 1818, Sir Humphry Davy† quoted letters from managers who were using his lamp in the North of England, Whitehaven, and Wales. John Buddle† had a proper lamp-keeper, to whom the "Davys" were brought by the colliers when they had finished work; this official unlocked the lamps, retained the bottoms for cleaning and refilling with oil, and handed the wire-gauze cylinders to the workmen, who took them home to clean them. When the men returned to work, the lamp-keeper inspected the gauzes, rejecting any that were defective; he then put the lamps

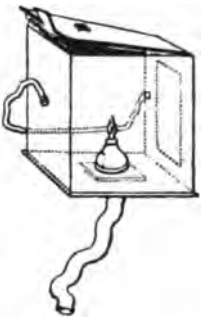

FIG. 21.—MR. R. W. BRANDLING'S LAMP.

Figs. 20 and 21 are reproduced by permission from the "Presidential Address" of Mr. J. R. R. Wilson to the Midland Institute of Mining, Civil, and Mechanical Engineers, *Trans. Inst. M.E.*, 1906, vol. xxxii., page 282, figs. 5 and 6.

* *The Philosophical Magazine and Journal*, by Alexander Tilloch, 1816, vol. xlvii., page 49.

† *On the Safety Lamp for Coal Miners*, by Sir Humphry Davy, 1818, page 127.

together, locked them, and handed them to the men; during the shift the lamp-keeper exercised a general oversight over the lamps, and replaced those which had been extinguished: "Davy-boys" seem also to have been employed for taking such lamps to the relighting station. Doubtless similar precautions were observed at other collieries. In order to check the wire-gauze supplied, Buddle* was in the habit of carrying a small piece of standard gauze for comparison; he had also a small lens, in the frame of which was an aperture ¼ inch square, and by counting the number of apertures in this space he was able to ascertain whether the gauze was of the correct gauge or not.

The safety-lamp does not, however, appear to have been adopted as generally as might have been expected, and even as late as 1835 mixed lights were extensively used. The reasons given for this by the Select Committee on Accidents in Mines (1835) were too little light, and the difficulty of bringing that light to bear upon the work with precision. To these reasons Mr. R. L. Galloway† adds the introduction at this period of gunpowder for blasting in coal. In some cases the safety-lamp was used chiefly for the purposes of exploration and trial.

In France the Davy lamp was known shortly after its invention. In 1816 MM. Baillot, Laporte, and Lefroy carried out tests on the lamp in the laboratory of the Royal School of Mines, an account of which and of the lamp was contributed by M. Baillot to the *Annales des Mines*,‡ with a strong recommendation for its use. In 1825 the Director-General of the Department of Public Works and of Mines (*des Ponts et Chaussées et des Mines*) issued a pamphlet entitled "Instruction pratique sur l'Emploi des Lampes de Sûreté dans les Mines,"§ in which an account was given of the Davy lamp, and various suggestions were made for improving its safety in case of long exposure to explosive mixtures of air and firedamp; directions were also given as to the locking, distribution, and cleaning of lamps. The "Instruction" also dealt with types of rescue-apparatus. From a circular which was sent out to the Prefects of Departments, with copies of the "Instruction" for distribution, it

* *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 2,217.

† *Annals of Coal Mining*, first series, page 510.

‡ 1816, series 1, vol. i., page 177.

§ *Ibid.*, 1825, series 1, vol. x., page 3.

appears that the Director-General had already ordered the exclusive use of safety-lamps in mines in which explosions had occurred or in which it was dangerous to use naked lights, and he urged the Prefects to make similar provisions in their Departments.

It appears that by 1825, 2,000 Davys were in use in the mines of Anzin. In that year the lamp was introduced into the mines of the Loire,* with the result that the death-rate from explosions was considerably diminished.

The Davy lamp was introduced into Belgium about the same time as in the North of France. In 1817 Davy lamps were already in use in the neighbourhood of Mons, and five or six years later they were adopted in the mines of Liége† and of Charleroi. In 1818 The Chamber of Commerce at Mons‡ issued a pamphlet entitled *Du Grisou, et des Moyens de preserver les Mines de Houille de son Inflammation* for the use of those interested in coal-mining in the province of Hainaut. In this a brief account was given of the observations which led up to the invention of the Davy safety-lamp, and directions were given for its practical use. Notes were added by M. Gossart, the President of the Chamber of Commerce, who had made experiments on the lamp.

In 1823 M. Chèvremont contributed a paper to the *Annales des Mines*§ on some improvements which he had introduced into the Davy lamp. He had substituted a copper cylinder perforated with fine holes for the upper portion of the Davy gauze and gauze-cap; he also used a slightly conical gauze, but rather for convenience in cleaning than because he considered it safer than the cylindrical form; he had improved the oil-admission tube, and suggested a different form of lock.

In Germany the safety-lamp was introduced about the same time in the Province of the "Bas-Rhin," forming part of

* *Mémoires Couronnés, Académie Royale de Belgique*, 1840; "Des Moyens de Soustraire l'Exploitation des Mines de Houille aux Chances d'Explosion," page 97. *Mémoire sur les Explosions dans les Mines de Houille et sur les Moyens de les Prevenir*, by M. A.-A.-M. Boisse, Ingénieur des Mines à Carnaux (Tarn).

† M. Renier Malherbe stated that in 1817 M. Orban ordered several Davy lamps made by Newman ("De l'Exploitation de la Houille dans le Pays de Liége," 1836, page 117).

‡ This account has been taken from *The Philosophical Magazine and Journal*, by Alexander Tilloch, 1818, vol. lii., page 137.

§ 1823, series 1, vol. viii., page 209.

Prussia. Official regulations respecting the use of safety-lamps were published on January 19th, 1818, for the district of Düren, and on March 3rd, 1818, for the district of Saarbrücken. Prof. Bischof, of Bonn, in 1840 stated that an experience of 22 years had proved favourable to the use of the safety-lamp.*

As time went on some doubt began to be expressed in Great Britain as to the safety of the Davy lamp, especially when it was exposed to currents of explosive mixture other than those moving at a low velocity. It has already been pointed out that Davy had foreseen this source of danger, and had suggested means of avoiding it; but he does not appear to have regarded it as likely to occur in practice, other than in exceptional cases.

Most of the witnesses connected with collieries who were examined before the Select Committee on Accidents in Mines (1835) were fully cognizant of the devices suggested by Davy to meet this danger. Mr. Ralph Elliott, overman at Penshaw Colliery, said that "with the Davy-lamp in my hand I have always considered myself as safe in an explosive atmosphere as I am sitting here, with proper precaution."† Mr. Buddle stated that the wastemen used shields upon their lamps. Mr. Wood believed the lamp to be safe, and that accidents happened through carelessness.

On the other hand, the scientific witnesses—Mr. Goldsworthy Gurney (a medical man, described as being engaged in mechanical and chemical pursuits); Dr. George Birkbeck; Mr. John Murray, Lecturer on Chemistry at Hull; Mr. Jonathan Pereira, Lecturer on Chemistry at the Medical School of the London Hospital; together with Mr. George Upton, lamp-maker of Cheapside; Mr. John Roberts, Mr. Upton's partner (who had been a working miner and had invented a form of rescue-apparatus—the "Roberts Safety-hood"), and Mr. James Ryan (a "Director of Mines," who had invented a species of gas-drain) considered that the lamp offered less security than was generally supposed, on account of the facility with which flame would pass in a current of explosive mixture. The usual method of experi-

* *Mémoires Couronnés, Académie Royale de Belgique*, 1840; "Des Moyens de Soustraire l'Exploitation des Mines de Houille aux Chances d'Explosion," page 345; "Mémoire sur l'Aérage des Mines," by M. Gustave Bischof, Professor de Chimie et de Technologie à l'Université de Bonn.

† *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 736.

menting appears to have been to hold the lamp against a jet of lighting-gas issuing from a gas-pipe; but Mr. Goldsworthy Gurney, in 1822, invented an apparatus (which was not described) in which he could obtain a current of explosive mixture of any velocity from 1 to 500 or 600 feet per minute. He found that in such a current, moving at a velocity of 300 feet per minute or faster, the Davy lamp would pass flame. In some tests Mr. Pereira mixed hydrogen with the coal-gas with which he was experimenting.

There seems to have been a feeling of disappointment that, after the introduction of the safety-lamp, the mortality due to accidents from firedamp had increased instead of decreased, as had been hoped. Possibly there may have been a tendency to overrate the efficiency of the safety-lamp. Mr. J. J. Wilkinson said:—

"Sir Humphry Davy's lamp, in my opinion, has suffered from the indiscreet zeal of his friends in not allowing it to be an imperfect instrument, or rather in insisting that it is completely perfect."*

On the other hand, since 1816 the output of coal had increased; the introduction of the safety-lamp had enabled more fiery seams to be worked than could be worked before its invention; while, according to Buddle, several collieries had "been re-opened by the aid of the Davy-lamp, which must otherwise have lain dormant."†

In 1835 a Select Committee on Accidents in Mines was appointed for Great Britain, and made its report on September 4th of that year. The committee devoted considerable attention to safety-lamps, but did not itself conduct any experiments upon them, although the members witnessed some tests conducted by Mr. Pereira at the London University. The lamps tested were the common Davy, the Davy with several seams, Dr. Clanny's "New" lamp, "Stevenson's"‡ lamp with glass, Ayre's improved "Stevenson,"‡ Robson's Bolton lamp, the Refrigerating lamp, Dillon's lamp, and the Upton & Roberts lamp. The last-named appears to have been the only one that did not pass flame.

In their Report the Committee expressed the opinion "that

* *Minutes of Evidence*, Select Committee on Accidents in Mines, 1835, Question No. 285. † *Ibid.*, Question No. 2,395.

‡ This is the way in which the name is spelt in the Report.

ignorance and a false reliance" on the merits of the Davy safety-lamp "in cases attended with unwarrantable risk, have led to disastrous consequences"; but a more extended use of the safety-lamp was recommended—"in some mines, now lighted by the ordinary means, the use of the lamp ought to be compelled by the owners." The Committee neither condemned nor recommended any particular type of lamp, although the opinion was expressed of the Upton & Roberts lamp that "its construction possesses paramount merit," and that the lamp would "supply a grand desideratum" if certain alterations could be made "to allow of more light with safety."

FIG. 22.—THE UPTON & ROBERTS LAMP.

Reproduced by permission of the Authorities of the Science Museum, South Kensington, from the example in the collection of safety-lamps at South Kensington.

The *Upton & Roberts lamp* (Fig. 22) was the result of experiments commenced in 1827 by George Upton, of Cheapside, and John Roberts.* It consisted of a gauze cylinder of Davy type enclosed by a cylinder of glass; above the glass, and fitting tightly on to it, was a metal chimney 2½ inches high, the diameter of which was 1¾ inches at the base, and 1¼ inches at the throat; the top was perforated so as to allow of the escape of the products of combustion. Air entered the lamp through horizontal apertures just above the oil-vessel, and then passed through a double layer of horizontal gauze into a cone, by which

* Mr. John Roberts was awarded the Silver Vulcan Medal and ten guineas by the Royal Society of Arts in 1826, and the Silver Isis Medal in 1829 for improvements to the Davy safety-lamp (*Transactions* of the Royal Society of Arts, 1826, vol. xliv., page 26; and 1829, vol. xlviii., part 1, page 121).

it was directed on to the wick. An Upton & Roberts lamp was tested by the British Royal Commission of 1886.

*M. Mueseler*, in Belgium, appears to have invented a similar lamp in 1829, which was tested by the Belgian Commission of 1836-1841.

*Mr. John Martin's lamp* had its air-inlet through deep apertures below the flame. The body was a metal cylinder with a glass lens at one point. The outlet from the lamp was first through a copper top perforated with small openings, then came "the break"—a device to deflect the products of combustion close to the sides of the metal cylinder; above this was placed a second copper cylinder, also perforated with holes. An illustration of this lamp was appended to the Report of the Select Committee of 1835.

Various modifications of the Davy lamp brought out during this period were the undermentioned:—

*Dr. Clanny's "New" lamp* (his fourth lamp). This was a Davy lamp fitted with an extinguisher consisting of three shields, sliding one over the other like the divisions of a telescope. When pushed up, this arrangement exposed about two-thirds of the gauze cylinder, and it was held in its place by a thin brass wire. In an inflammable atmosphere the heat fused the brass wire, and so allowed the shield to drop down, leaving exposed a small strip of gauze below the shield for the admission of air. The flame of the burning gas was extinguished, but a small oil-flame continued to burn, enabling a person to get away from the place.

*M. Agre* also devised a self-extinguishing arrangement, consisting of an iron disc held up by a hook made of easily fusible metal.

*Mr. John Newman*, of 7, Lisle Street, London, who originally made lamps for Sir Humphry Davy, invented a Davy lamp with a second gauze cylinder surrounding the first, leaving a space of ¼ inch between them. The outer cylinder only protected the upper part of the lamp, and did not come down low enough to cover the flame; it could, however, be made to slide up or down at pleasure. He also applied a glass lens to the lamp, so as to improve the light.*

*M. Gossart* and *Mr. J. Roberts* applied reflectors to the lamp,

*An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

and *Mr. Francis Ellis*, of Bath, used a plano-convex lens externally to improve the light.

*Mr. John Dillon*, of Belfast, brought out a lamp constructed similarly to the Davy, but the gauze was larger; it had three wicks, and was covered externally with a mica shield.

*The Refrigerating lamp* was invented by Mr. Wood, of Killingworth, and is stated to have combined the principles of both the Davy and the Stephenson lamps. In it an upper chamber was surrounded with water to cool down the heated gas, which passed off through the top of the lamp.

The alterations in the Davy lamp made by Chèvremont have been already mentioned. It is probable that some of the lamps examined by the Belgian Commission of 1836-1841, and described in Section X., were invented in the period under review.

## X.—PERIOD 1836 TO 1843.

This period is one of the most interesting in the history of the safety-lamp. It includes two important investigations—one conducted by the Belgian Commission, the other by the South Shields Committee, and the invention of two safety-lamps of considerable importance—the Mueseler and the Clanny (sixth type).

On April 13th, 1836, the Belgian Government appointed a Commission at Liége to test safety-lamps and to report upon them. The apparatus used allowed of the speed of the explosive mixture and the position of the lamps being varied, while the composition of the explosive mixture could be ascertained. Either lighting-gas, or hydrogen, mixed with air, could be used.

Among the lamps tested were the Davy, two lamps of M. le Sous-Ingénieur Mueseler, the lamp of M. Cambrésy and of M. le Baron Eugène Dumesnil (also spelt Du Mesnil), and the Upton & Roberts lamp.

The First Report of the Commission,* dated April 25th, 1840, stated that, while the Davy lamp left a good deal to be desired from the point of view of safety, the Commission had been unable to find among any of the lamps tested one to take its place, except the Dumesnil lamp, of which they had evidently

* *Annales des Travaux Publics de Belgique*, 1843, vol. i., pages 309-327.

formed a favourable opinion. They recommended that a practical test of this lamp should be made by distributing a dozen Dumesnil lamps among intelligent miners in fiery collieries, and that the result should be watched.

The Commission issued a Second Report on August 31st, 1840. The Dumesnil and Lemielle lamps had been tested, and also another lamp submitted by M. Mueseler—the well-known chimney lamp. The Commissioners recommended that these three lamps should be permitted for use, provided that their construction and proportions were the same as those of models deposited in the bureaux of the "Ingénieurs des Mines," and that practical experience would be thus gained from the use of these lamps underground. The Commissioners spoke in very favourable terms of the Mueseler lamp, and stated that in their opinion it was the best. The Commission presented a Third Report* on August 30th, 1841, which dealt chiefly with trials which had been made with the Mueseler lamps in practical use at some of the Belgian collieries; with various improvements in detail, such as locking of lamps; and with new forms of lamps presented by M. Lemielle and M. Rocour. The Report confirmed the previous favourable impression of the Mueseler lamp, and recommended that the inventor should be suitably rewarded.

On June 28th, 1839, an explosion occurred at St. Hilda Colliery, South Shields, and shortly afterwards a committee was appointed at a public meeting at South Shields to investigate the causes of accidents in coal-mines. The president of the committee was Robert Ingham, there were eight other members, and the Hon. Secretaries were James Mather and Thomas Salmon. The subject of safety-lamps was fully investigated by the committee, which issued its Report in 1843.†

The following lamps were brought before the committee and tested by it:—The Davy, the Stephenson, the lamps of Mr. Henry Smith, Dr. Clanny (fourth and fifth types, and probably the sixth type), Upton & Roberts, Mr. William Martin, and

* *Annales des Travaux Publics de Belgique*, 1843, vol. i., pages 328-339.

† In the *Second Report of the Royal Commission on Mines*, 1907, page 3, the date is given as 1842, but the Report itself is dated 1843; and in the *Report on the Gases and Explosions in Collieries*, by Sir Henry de la Beche and Dr. Lyon Playfair of August 27th, 1845, the date of the Report of the South Shields Committee is given as 1843.

Mr. Richard Ayre. The committee was also furnished with a copy of the Reports of the Belgian Commission of 1840, and with specimens of the Mueseler and Lemielle lamps.

The committee arrived at the following conclusions:—

"no mere safety lamp, however ingenious in its construction, is able to secure fiery mines from explosion; and that a reliance on lamps alone is a fatal error, conducive to those dreadful calamities which they are intended to prevent. . . . . the naked Davy lamp is, without a complete shield, a most dangerous instrument.

"the best description of lamp to be employed is that on the principle of the Improved Clanny and the Mueseler lamps, the latter with a continuous gauze cylinder."

It was suggested further that great care should be exercised in the daily examination of safety-lamps and their use.*

In 1840, or a little earlier, some important tests on the Davy safety-lamp were carried out by Dr. Gustave Bischof,† Professor of Chemistry and Technology in the University of Bonn, who conducted his experiments with gas from blowers at Saarbrücken. He seems to have agreed generally with Davy's results, but found that the degree of inflammability of the gas which he used for testing varied, and considered that in every mine lamps with different sizes of gauze should be provided.

The lamp invented by *Baron Eugène Dumesnil* (Figs. 23, 24, and 25) had its oil-reservoir placed to one side, and was fitted with a flat wick. The feed-air entered the lamp through two inclined channels or tubes ¼ inch (6 millimetres) wide, covered with metallic gauze. The flame was surrounded by a thick glass cylinder, above which was a chimney, the diameter of which was considerably less than that of the glass. This chimney was double, the inner portion descending a little way into the body of the lamp, where it was widened out.‡ The chimney was narrowed down to a very small diameter at the outlet, which was originally protected by gauze; but it was found that this render-

* *The Report of the South Shields Committee appointed to Investigate the Causes of Accidents in Coal Mines*, London, Longman, Brown, Green, & Longmans, 1843. This Report was reprinted as appendix iv. to the *Report from the Select Committee on Coal Mines*, 1852, page 155.

† *Mémoires Couronnés*, Académie Royale de Belgique, 1840, vol. i.; "Des Moyens de Soustraire l'Exploitation des Mines de Houille aux Chances d'Explosion," page 205; "Mémoire sur l'Aérage des Mines."

‡ "Où elle s'évase en forme d'entonnoir renversé," *Traité de l'Exploitation des Mines*, by Ch. Combes, 1844, vol. ii., page 597, and fig. 5, plate xxviii. An external view of the lamp is given in *Historia, Descripcion, y Crítica de las Sistemas Empleados en el Alumbrado de las Excavaciones Subterráneas*, by A. Gil y Maestre & D. de Cortazar, Madrid, 1880.

ed a prolonged use of the lamp impossible. In the presence of gas in quantity, the lamp emitted a sound.* This lamp was presented to the Academy of Science in Paris in 1838.

*M. Mueseler* invented a double-gauze lamp, apparently of the Davy type, and *M. Cambrésy of Liége* produced a lamp called "Soleil de Nuit," also with metallic gauzes.

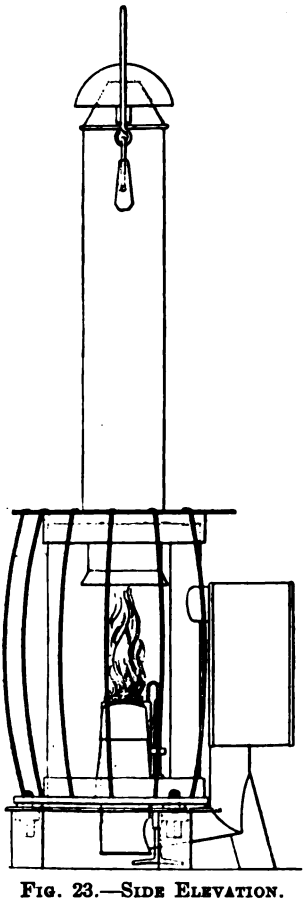

FIG. 23.—SIDE ELEVATION.

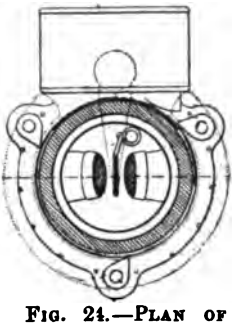

FIG. 24.—PLAN OF AIR-INLET CHANNELS AND WICK-TUBE.

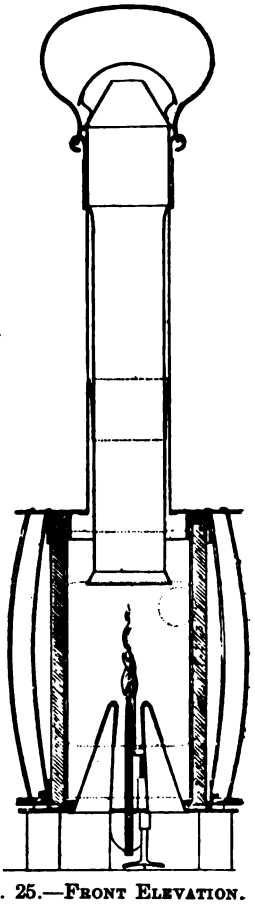

FIG. 25.—FRONT ELEVATION.

FIGS. 23, 24, AND 25.—THE DUMESNIL LAMP.

Reproduced by permission of the President of the Commission of the Annales des Mines from an illustration accompanying a paper by M. Gruner in the *Annales des Mines*, 1839, series 3, vol. xvi., page 511.

*"La lampe . . . . fait entendre, quand l'hydrogène abonde, un son de corneuse qui justifie ce mot de l'auteur, que sa lampe crie dans le danger" (First Report of the Belgian Commission, April 25th, 1840, *Annales des Travaux Publics de Belgique*, 1843, vol. i., page 314).

*Mr. Richard Ayre* submitted two Davy lamps to the South Shields Committee, one with an arrangement by which the light was extinguished when the bottom was unscrewed; the other the "Barometer" lamp, to which air passed through a valve which closed when the atmosphere became filled with "foul" gas, thus extinguishing the flame.

*Mr. Henry Smith's* lamp was an improved Stephenson, invented probably about 1841. Air was admitted below the flame through perforations in the underside of a shoulder or rim, the interior of which was hollow. The chamber thus formed was protected by gauze.

In *Mr. William Martin's* lamp air was admitted through small perforations in a metal ring below the flame. The outlet is stated to have been through a copper chimney contracting gradually to a cone, "something similar to Upton and Roberts'." The flame was surrounded by a glass cylinder unprotected by gauze, for which reason the South Shields Committee objected to the lamp.

*Dr. Clanny* submitted his fourth lamp, the one which he had already brought before the Select Committee on Accidents in Mines (1835), to the South Shields Committee, and a description of it was given in their Report.

*Dr. Clanny's fifth lamp* (the "Improved" lamp) was described to the South Shields Committee in a paper read by him on August 17th, 1839. It appears to have consisted of an internal gauze cylinder, which was completely surrounded by an impervious metal shield, having glass and lenses in its side. This shield was "only open at the highest part of the gauze cylinder for about 1½ inches from the top," the shield being fully half an inch larger in diameter than the gauze cylinder. Consequently, there was no admission or egress of air except over the top of the shield at the highest part of the lamp. The lamp behaved well in experiments conducted at Wallsend Colliery. It was subsequently modified by surrounding the portion opposite to the flame with "a thick globular* shield

*The meaning of the words "globular" and "globe," applied by the South Shields Committee to the glass of Dr. Clanny's lamps, is not very clear. In his evidence before the Select Committee of the House of Lords (1849, Question No. 4,667), Dr. Clanny said: "I first used lenses, and they answered very well, but they threw the light to such a distance, that I was compelled to have made glass cylinders for the express purpose." The convex surface of a cylindrical glass lens would give the glass a "globular" appearance.

of glass," the metal shield being continued upwards from the glass. The lamp was praised by the committee, and was considered superior to any lamp that the committee had "yet" examined, although it was not "the desideratum so much sought after—in all points a perfect safety lamp." Objections to it were its weight, 2 pounds 6 ounces, and the risk of fracture to the glass, which "would then only render it a Davy lamp."

This lamp has been described in detail, because it was the first constructed on the principle of supplying air for combustion from *above* the flame, so that the application of this principle, so largely adopted in subsequent lamps, must be ascribed to Dr. Clanny.* This principle was one of the points in the Mueseler lamp especially praised by the Belgian Commissioners in their Second Report of 1840—"La commission a vu un perfectionnement d'une grande portée dans la disposition qui consiste à faire arriver, par le haut, et non par le bas, l'air destiné à la combustion de la mèche."

The South Shields Committee in their Report of 1843† pointed out, however, that the merit of the discovery of this principle was due entirely to Dr. Clanny, who had explained the construction of his lamp (the fifth Clanny lamp) to them on August 17th, 1839, almost exactly one year previous to the date (August 18th, 1840) on which Mueseler's lamp was submitted to the Belgian Commission.

It seems probable that *Dr. Clanny's sixth lamp*—the well-

* It is possible that the first application of this principle should be ascribed to Sir Humphry Davy or to a Belgian inventor. In his book *On the Safety Lamp for Coal Miners* (1818, page 142), Sir Humphry Davy wrote: "I have often made lamps in which surfaces of glass were used for transmitting light without a guard of wire gauze, they give more light, but they are highly dangerous, and ought never to be used. Thick plates of mica (Muscovy glass,) may, however, be safely employed, though great care must be taken in this case that the radiating and cooling surfaces, where the firedamp burns, are extensive." In a footnote he mentioned a case of breakage of a glass in the colliery of Tapatouts in Flanders:—"A director of the works having descended in the colliery of Tapatouts, with a lamp of which the base of the cylinder was of glass, a drop of water fell upon and broke the glass."

The writers have found no detailed description of either the lamp of Davy or the Belgian lamp; a lamp of this construction might have derived its air either from above the flame, like Clanny's, or from below the flame, like Boty's. In the former case it seems strange that neither the South Shields Committee nor the Belgian Commission was aware that such a lamp had been previously constructed; on the other hand, on the next page in the book mentioned above Sir Humphry Davy proceeded to discuss a lamp of under-air-feed type with which he had experimented, as though its principle was quite different. The Tapatouts lamp was mentioned by the South Shields Committee as an example of the danger of using glass unprotected by gauze.

† Page 25.

known Clanny lamp, or an earlier form of it,* was submitted to the South Shields Committee. On page 20 of the Committee's Report allusion was made to a lamp of Dr. Clanny's other than the two already mentioned—"A lamp which the Doctor has placed before the Committee on this principle [the admission of air from above the flame], but with a naked projecting globe of strong glass, without any external wire gauze, is perfectly inadmissible for the reason just assigned—the facility of fracture of the glass."

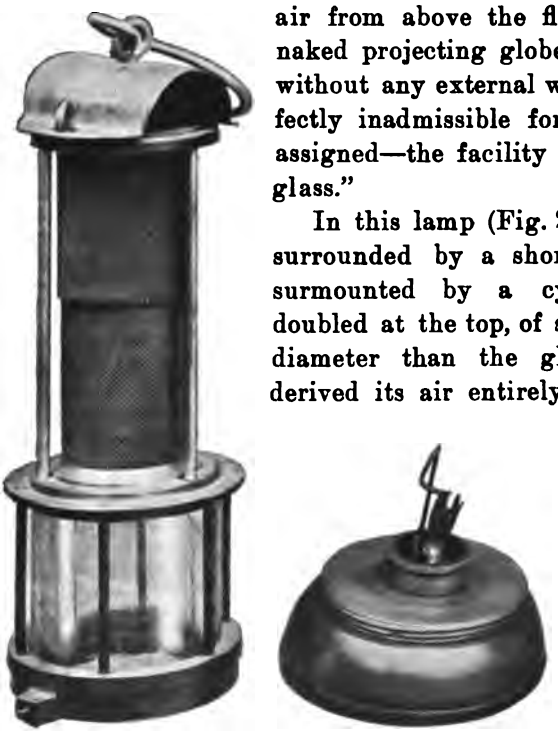

FIG. 26.—DR. CLANNY'S LAMP (SIXTH TYPE).

Reproduced by permission of the Authorities of the Science Museum, South Kensington, from a photograph of the Clanny lamp in the collection of safety-lamps at South Kensington.

In this lamp (Fig. 26) the flame was surrounded by a short glass cylinder surmounted by a cylindrical gauze, doubled at the top, of somewhat smaller diameter than the glass. The lamp derived its air entirely from above the top of the glass, through the lower portion of the gauze cylinder. Some of the early forms of this lamp appear to have had very fine gauzes, up to 1,296 "meshes" to the square inch, but 1,000 is stated to have been more usual.

*Mr. Matthias Dunn, in *A Treatise on the Winning and Working of Collieries* (1852, page 160), described, with an illustration (fig. 6, plate x.), "a more improved lamp of Dr. Clanny, the amended principle of which, as will hereafter appear, consists of the wire gauze being supplanted by a copper tube, perforated with innumerable holes, through which air passes and descends to the flame, as in his steam lamp. But this lamp was at length far surpassed by his glass lamp, very nearly similar in form, and coeval in invention with the Belgian lamp of Mueseler." On page 247 he mentioned the lamp of M. Mueseler, "which, by one of those coincidences not at all uncommon, occurred nearly two years after the improved lamp of Dr. Clanny, upon the same principle, but at such a period as to leave undisputed the priority of the invention of the latter gentleman."

Some authorities indicate the year 1839 as the date of the invention of this lamp, and thus claim priority of invention for the sixth type of Clanny lamp (the best known of all the Clanny lamps) over the Mueseler.* But the fact that the lamp may have been alluded to in the Report of the South Shields Committee in the words quoted above is only proof that it was in existence before 1843, the date of publication of the Report. Dr. Clanny, in his evidence before the Select Committee of the House of Lords (1849),† stated that he was performing experiments with a safety-lamp "in 1841 or 1842 or 1843," and this lamp appears to have been the well-known Clanny lamp, of which an illustration was given (inset in Dr. Clanny's reply to Question No. 4,674). He further stated that only seven of these lamps were made by Mr. J. Mills in 1843. Mr. Mather in his evidence, in reply to Question No. 3,673: "The South Shields Committee expressed an opinion principally in favour of the Clanny lamp and the Mueseler lamp?" stated "Yes; Dr. Clanny, by way of giving more light, since has discarded the gauze, and I think rendered the safety of the lamp much less than it was before."

A sketch of the lamp was given in the *Mining Journal* for November 14th, 1843,‡ and in a previous number (September 16th§) the statement was made that Dr. Clanny had invented his lamp twelve months before Mueseler. The question as to priority between Clanny and Mueseler was also alluded to in letters from Mr. J. Murray to the *Mining Journal* of 1844. Allusion has already been made to Mr. Dunn's statement (made in 1852) that the Clanny glass lamp was coeval in invention with the Mueseler lamp.

It is possible that confusion may have arisen between priority of discovery of the principle of admission of air above the flame, and priority in producing a lamp of that particular construction.

Dr. Clanny contributed some notes on his lamp to the Royal Society of Arts on March 25th, 1846. The Society submitted

* This question was discussed by Mr. R. L. Galloway in *The Annals of Coal Mining*, second series, page 317.

† Question No. 4,664.

‡ Vol. xiii, page 367.

§ *Ibid.*, page 301.

the lamp to their Committee of Chemistry, which considered the subject on April 16th and May 7th, 1846. Several persons connected with collieries, chiefly in the North of England, testified in its favour. The committee, however, could not undertake the responsibility of recommending a new lamp.

Subsequent investigation has shown that the Clanny lamp offered "very little more security than the Davy lamp." The British Royal Commission of 1886 found that "it is almost certain to cause an explosion in a current having a velocity of 600 feet per minute, if the mixture of gas and air is readily explosive." When bonneted, however, "as proposed by Mr. William Smethurst and Mr. Ashworth," the Commissioners found that the lamp became much more trustworthy, and did not appear dangerous in currents with a velocity of 1,500 feet per minute, or even 1,900 feet per minute, "but an explosion was produced when the current velocity was increased to 2,857 feet per minute."

The *Lemielle lamp* was described by the South Shields Committee of 1843 as a Davy lamp with a glass inside admitting air through a treble gauze, "in an improved mode." The glass cylinder extended a little more than half-way up the interior of the gauze cylinder, which was $6\frac{1}{2}$ inches high and $1\frac{4}{10}$ inches in internal diameter. Air entered below the flame through three thicknesses of gauze, protected by "a projecting piece of brass." It weighed 1 pound $10\frac{1}{2}$ ounces, and appears to have been patented in Belgium on July 15th, 1840, by T. Lemielle, of Liége.

The *Mueseler safety-lamp* was the invention of a Belgian, M. le Sous-Ingénieur Mueseler, and was tested by the Belgian Commission on August 18th, 1840. Presumably, this is the lamp to which the Belgian patent of September 15th, 1840, refers. The patent was for improvements to a safety-lamp already patented (*breveté*) on December 23rd, 1829, and was granted to L. Mueseler, of Liége. It was fully described by the South Shields Committee of 1843, from whose report the following account is taken.

The lamp (Fig. 27)* was about 10 inches high, including the oil-vessel. Around the flame was a very strong glass, $\frac{1}{4}$ inch

*M. Joseph Mulkay, lamp-maker, was described by M. Em. Harzé as having been M. Mueseler's zealous and intelligent assistant in the design of his lamp (*Annales des Mines de Belgique*, 1906, vol. xi., page 83).

thick, "formed like an ordinary drinking glass, without a bottom," which was $3\frac{1}{2}$ inches high and $1\frac{3}{4}$ inches in internal

FIG. 27.—DETAILS OF MUESELER LAMP.

Reproduced by permission of the Authorities of the Science Museum, South Kensington, from a photograph of the Mueseler lamp (received in 1844) in the collection of safety-lamps at South Kensington.

diameter. On the outside of the glass cylinder was "a sort of shield, of eight ribs of iron, placed edge-ways, vertically," to

serve as a protection to the glass. Placed above the glass and forming a continuation to it was a wire-gauze cylinder 4½ inches high and 1¾ inches in internal diameter, having a brass top full of minute perforations. The glass and wire-gauze, closely united, made a continuous cylinder about 8 inches high, having a piece of wire-gauze stretched across the internal area at the junction of the two substances, over the top of the glass. Through the centre of this piece of horizontal gauze was a small metal chimney to convey from the flame of the lamp the smoke and "de-oxygenated air." The chimney passed down to within an inch of the wick; it was 4 inches high, about $\frac{7}{10}$ inch in diameter at the bottom, tapering to $\frac{4}{10}$ inch in diameter at the top, and rose to discharge the smoke, etc., about half-way into the interior of the wire-gauze cylinder. The lamp weighed 2 pounds 11 ounces.

The Belgian Commission spoke most highly of the lamp, which they considered united all the essential conditions of a good safety-lamp in a much higher degree than any of the lamps that they had hitherto tested; it had even proved to be safe in an explosive atmosphere when deprived of its gauze cylinder.*

The South Shields Committee thought well of the lamp, but recommended the use of a continuous gauze. The writers are not aware whether such a modification of the lamp was made at so early a date.

By Royal decrees of October 19th, 1840, and August 8th, 1842, two sums of 2,000 francs each were awarded to Mueseler; the latter decree raised him to the rank of "Ingénieur des Mines de 2$^{me}$ Classe." The jury of the Belgian Exhibition in 1841 awarded Mueseler a gold medal. The feeling in Belgium in favour of the Mueseler lamp was still further shown by the publication on December 15th, 1842, of the "Instruction Pra-

* The passages read as follows:—"Elle a soutenu les épreuves de la manière la plus satisfaisante, et a été unanimement considérée comme réunissant, à un plus haut degré que toutes celles essayées jusqu'ici, les conditions essentielles d'une bonne lampe de sûreté . . . . Mais le fait le plus concluant en faveur de l'explication ci-dessus" [this refers to a previous paragraph] "est celui qu'a présenté la lampe Mueseler, d'être de sûreté, dans un mélange d'hydrogène pur et d'air, lors même qu'elle était privée de son cylindre métallique; ce qui ne peut s'expliquer que par l'épanchement d'une fraction des produits de la combustion, autour de la partie inférieure de la cheminée; épanchement qui aurait suffi pour rendre inexplosif le mélange d'air et d'hydrogène arrivant sur la mèche"; "Second Report of the Belgian Commission," August 31st, 1840 (*Annales des Travaux Publics de Belgique*, 1843, vol. i., pages 325-326).

tique sur l'Emploi de la Lampe de M. l'Ingénieur Mueseler, rédigée par Ordre du Ministère des Travaux Publics."*

If the Mueseler lamp is inclined, the flame is quickly extinguished; this constitutes a serious inconvenience, and was the cause of some of the numerous variations on this type of lamp that were made in subsequent years. When the lamp is vertical, the products of combustion pass away up the chimney; but when the lamp is inclined, the heated products of combustion strike on one side of the gauze diaphragm which holds the chimney in place, and the products of combustion which have already entered the chimney descend on to the flame, and soon extinguish it. For this reason in British types of this lamp the distance between the bottom of the chimney and the flame was greater than in the standard Belgian Mueseler, a modification which did not seriously affect the safety of the lamp. The safety of the lamp is also liable to be affected by variations in the relative proportions in the parts of which it is composed.

The amount of security afforded by the Mueseler lamp was a subject of investigation for many years and in several countries. The British Royal Commission on Accidents in Mines (1886) pointed out that—

* "Though the Belgian Mueseler is a very safe lamp in a current which strikes it approximately at right angles to its axis, and which is nearly uniform over the whole of the lamp, this is very far from being the case when the lamp receives the current obliquely, and is partially shielded from its action."†

This source of danger had already been pointed out by the Belgian Commission of 1867-1873. The bonneted Mueseler, however, was one of the lamps specially commended by the British Commission of 1886.

The Mueseler lamp continued to occupy a favoured position in Belgium almost from the time of its invention up to 1904.

On August 11th, 1841, a regulation respecting mines was issued for the Province of Hainaut, containing the coalfield of Mons and Charleroi, Article 18 of which directed that only safety-lamps were to be used in mines in which the presence of firedamp had been detected.

In 1841 *M. Lemielle* submitted to the Belgian Commission a lamp having two gauze cylinders and two glasses: the inner gauze cylinder was made with very fine apertures.

* *Annales des Travaux Publics de Belgique*, 1843, vol. i., page 540.

† Final Report, page 81.

*M. "le Conducteur des Mines" Rocour* submitted a lamp which had two glass cylinders around the flame. It appears to have been an altered form of Mueseler. Air for combustion passed to the flame through the space between the two glasses, and through a ring of gauze placed near to and below the wick-tube. This arrangement was designed to meet the difficulty experienced from the liability of the Mueseler to extinction when tilted.

In the same year *M. Planque* designed a lamp intended for use at "*chargeages*,"* which was a combination of the Dumesnil and Mueseler lamps.†

Up to this time considerable distrust appears to have been felt in Great Britain towards lamps in which the flame was protected only by glass, a feeling which is reflected strongly in the Report of the South Shields Committee. In order to obviate this difficulty, in 1841 M. Goleuni of Llanelly wrote to the *Mining Journal*‡ suggesting a lamp, chiefly for the use of viewers and overmen, with a double glass, the space between the two glasses being filled with water; the lamp was to take in air below the glasses, while the products of combustion left the lamp through a gauze "chimney."

In Belgium similar objection does not appear to have been taken to the use of glass unprotected by gauze, as in the two lamps recommended by the Commission of 1836-1841 (the Dumesnil and the Mueseler) the flame was surrounded by a glass cylinder alone.

## XI.—Period 1844 to 1866.

In Great Britain during the earlier part of this period a good deal of attention was given to accidents in mines. Between 1849 and 1854 three Select Committees, one of the House of Lords, and two of the House of Commons, examined a number of witnesses either connected with or interested in the mining industry, and issued reports on the subject. These enquiries hardly exercised any direct influence on the development of the safety-lamp, for none of the committees conducted any independent tests on

* This word refers to hanging-on, or onsetting, at the shaft.

† Third Report of the Belgian Commission, August 30th, 1841, *Annales des Travaux Publics de Belgique*, 1843, vol. i., pages 332-339.

‡ 1841, vol. x., page 30.

lamps, and no opinion was expressed about any lamp except the Davy. On the other hand, the experiments of Nicholas Wood and T. J. Taylor seem to show that the need for such tests was recognized. Dr. Bachhoffner also conducted experiments, but the writers have failed to trace any account of his method of testing lamps.

The most important lamps brought out were the Boty and the Eloin. The former was used somewhat extensively on the Continent, while the latter is interesting because it introduced a type which was followed by several subsequent inventors. The Tin-can Davy appears to have been the first form of completely encased Davy. An interesting feature is the number of lamps into which air entered from below the flame—in some cases directly; in others indirectly, through the space between two concentric glasses. From this it would appear that the principle of supplying safety-lamps with air from above the flame—the principle so much admired by the South Shields Committee in the Clanny lamp of 1839, and by the Belgian Commission of 1836-1841 in the Mueseler lamp—had not yet obtained general approval. Admission of air below the flame probably appeared preferable as being the method adopted in all other kinds of lamp, and as being conducive to the provision of a better light.

Several of the lamps mentioned were fitted with two glasses. In some of them this was doubtless due to distrust of a single glass; in others, the space between the glasses was utilized to enable the air to enter below the flame, through more than one gauze. In those lamps, however, in which the inner glass was contracted into a chimney, the object was probably to create a better draught through the lamp, and thus to improve the light.

Many inventors turned their attention to devices intended to prevent lamps from being opened in the pit, the flame being extinguished when an attempt was made to withdraw the oil-vessel. Exclusive of those mentioned in the text, no less than twenty patents were taken out for arrangements to ensure this object. Improved locks were also devised, some of them pneumatic. Attempts were also made to improve the light given by the safety-lamp by the use of lenses, improved burners, and mineral oils, such as naphtha, paraffin, and petroleum.

The Belgian regulations respecting safety-lamps are an interesting feature of this period. It has already been pointed

out that the Belgian Commission of 1836-1841 attached great importance to the principle that the dimensions of the parts of lamps in use should conform exactly to those of the lamps of each type which had been tested: since that time this principle has always been recognized by Belgian legislation, and has more recently been adopted in France and in Great Britain. The Commission also suggested that certain types of lamp should be permitted for use in collieries experimentally, in order to see how they stood the test of practice. This idea was adopted in the provisional regulation of 1851; but the result appears to have been wholly favourable to the Mueseler lamp, which towards the end of this period became the safety-lamp *par excellence* in Belgium, to the exclusion of other types. The Belgian Government, therefore, assumed the responsibility, not only of prescribing one particular type of lamp, but also of deciding what should be its dimensions—variations within certain limits being allowed. This policy has often been criticized as tending to limit the work of inventors to one type of lamp only, and in that way to prevent the development of other types. No doubt this objection would have had greater weight if a similar restriction had been imposed in other countries interested in the mining of coal.

No special activity in respect to the safety-lamp appears to have been shown in France, for M. Amadée Burat, writing in 1861,* remarked that the Davy lamp was almost the only one in use in France, and regretted that no official announcement had been made as to the best type of lamp. He quoted the example of the Belgian Government, and expressed the opinion that the Mueseler was an improvement on the Davy lamp.

In Germany lamps of the Boty type, such as the Herold, Westphalian, and Saarbrücken lamps, appear to have been in use.

Patents for portable electric lamps were taken out in this period, one of the earliest† being that of William Clark in 1859. This idea was not altogether new, as Sir Humphry Davy experimented with "electric light in close vessels" before he discovered the properties of wire-gauze. Methods for indicating the condition of the atmosphere in mines by other means than the flame-

* *Matériel des Houillères en France et en Belgique*, 1861, page 190.

† Mr. R. L. Galloway in his *Annals of Coal Mining*, series 1, page 324, gives some earlier instances than the one mentioned above.

test were devised by Warrick (in 1842), Beaumont, Addison, Gisborne and Wickens, Moore, and Ansell. The problem of lighting mines with fixed gas-jets, the burners being either protected or unprotected, occupied several inventors, one of the earliest being James Murray, in 1844. Schemes for supplying lamps underground, either portable or fixed, with air through pipes were also brought forward.

*Boty Lamp* (Fig. 28).—This was presumably the lamp patented by A. Boty* of Wames on January 11th, 1844, the patent being for improvements to the Davy. The flame was surrounded by a cylinder of glass, which was surmounted by a gauze-cap; this cap was made slightly conical, its diameter at the bottom being the same as that of the inside of the glass. In the original form the air entered the lamp through very small inlet-holes in the ring below the glass, as in lamps following the Stephenson type. In another form of the lamp, however, this ring was not pierced with holes, so that the air entered above the flame through the lower portion of the gauze cap, as in the Clanny.

This type of lamp appears to have been regarded with some favour on the Continent, and the lamp of Königlicher Bergmeister Herold, introduced about this time into the Westphalian coalfield, was similar to the Boty, the air-inlet being through a row of apertures in a metal ring below the flame, protected further by a horizontal ring of gauze. A conical metal ring directed the air on to the flame, and served as a reflector.†

Other varieties of the Boty lamp were the Westphalian and Saarbrücken lamps in Germany, and the Porion lamps in Belgium.

The *lamp of M. Combes*, tested on April 30th, 1844,‡ admitted air to the flame through holes in the brass ring below the glass, and through two or three gauze diaphragms, having a guide-plate to direct the entering air on to the flame. It had a

* M. Ponson described him as "Directeur Gérant de Haut Flénu" (*Traité de l'Exploitation des Mines de Houille*, by A. T. Ponson, Liége, 1853, vol. ii., page 288).

† Berginspektor Fähndrich, *Die Entwickelung des Niederrheinisch-Westfälischen Steinkohlen-Bergbaues in der zweiten Hälfte des 19ten Jahrhunderts*, vol. vii., page 221.

‡ "Resultats des Essais faits avec la Lampe Combes," by M. Lefrançois, Ingénieur des Mines, Chargé du Sous-arrondissement d'Alais, *Annales des Mines*, 1845, series 4, vol. vii., page 379.

circular glass, protected by standards, a cylindrical gauze-cap, and a cylindrical chimney held in place by a gauze diaphragm. The lamp was described as a "Dumesnil légèrement modifiée," but appears to have been a lamp somewhat similar to the Mueseler with air-feed below the flame.

The lamp, however, was made with air-feed above the flame, as well as with under air-feed.* In Marsaut's paper† it is shown

Fig. 28.—Boty Lamp.

Fig. 29.—Eloin Lamp.

Figs. 28 and 29 are reproduced by permission of the Authorities from lamps in the collection at the Science Museum, South Kensington.

with the air-feed from above the flame only, and similarly in the Report of the Sub-Commission on safety-lamps of the Prussian

* Report of the St. Étienne Commission, *Bulletin de la Société de l'Industrie Minérale*, 1867-1868, series 1, vol. xiii., page 723.

† *Ibid.*, 1883, series 2, vol. xii., page 321.

Fire-damp Commission.* The lamp seems, therefore, to have been capable of several modifications.

On June 29th, 1844, a police regulation respecting mines was issued for the Province of Liége, Belgium, which made the employment of safety-lamps approved by the Administration of Mines obligatory in certain specified mines. The "Ingénieurs des Mines" were invested with authority to decide in what parts of each colliery only safety-lamps were to be used, and the type of lamp to be employed.

The *Eloin* lamp (Fig. 29) was probably the lamp patented by F. Eloin of Namur† on February 16th, 1846; it was described as a modified safety-lamp, suitable for miners. The glass was "shaped‡ like a dice-box," and stood on a short metal cylinder; above the glass was a plain brass tube 1¼ inches in diameter, closed at the top by a gauze diaphragm, which was shielded by a metal dome. Air was admitted below the glass through large openings, protected by gauze, in the metal cylinder which supported the glass, the inlet being protected from the direct action of the air-current by a short conical shield; the entering air was directed on to the flame by a metal plate situated immediately above the inlet openings.

The British Royal Commission of 1886 found that the Eloin lamp as a general rule was at once extinguished in an explosive mixture. They considered it a very safe lamp, but stated that the flame was easily extinguished by any motion communicated to the lamp.

*Cosset-Dubrulle Lamp.*—This lamp, invented about 1847, was a Davy with a flat wick, and an automatic extinguishing arrangement to prevent the lamp from being opened.§ The oil-vessel was of a peculiar shape, like that of an urn.

*Eloin's Mueseler* was an altered form of Eloin lamp with a chimney. The under air-feed of the Eloin lamp was discarded, and air entered the lamp above the flame through a short cylinder of gauze inserted nearly at the bottom of the Eloin tube

* "Schluss-Bericht der Lampen-Unter-Commission," *Anlagen zum Haupt-Berichte der Preussischen Schlagwetter-Commission*, 1886, vol. iii.

† M. Ponson described him as "Officier des Mines, à Namur" (*Traité de l'Exploitation des Mines de Houille*, by A. T. Ponson, Liége, 1853, vol. ii., page 296).

‡ *Final Report of the Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 11.

§ *Annales des Mines*, 1847, series 4, vol. xi., page 105.

just above the glass; it then passed to the flame through a horizontal gauze diaphragm, which held the chimney in its place as in the Mueseler lamp. The chimney was cylindrical, long, and narrow: it descended well below the gauze diaphragm and was widened out above the flame, leaving only a small space between its edge and the glass for the passage of air to the flame.*

*Biram Lamp.*—The lamp patented† by Mr. Biram of Elsecar in 1849 (Fig. 30) consisted of a semi-circular case, into which the oil-vessel was made to slide. The case was surmounted by a chimney of metal, pierced at the top with slots guarded inside by gauze; alternatively a chimney of gauze could be substituted. The front of the case was closed by a frame made to slide downwards from the top in grooves at the sides of the case. The lower part of this frame carried a sheet of metal, in which openings were cut, protected by wire-gauze; the upper part carried a sheet of mica, through which the light of the oil-flame shone. The lamp in the Science Museum at South Kensington is furnished with an alternative frame for the front of the lamp, in which the lower portion is covered with a plain sheet of metal, the upper portion being covered with gauze. Either of these frames could be used. The patent provided also for the substitution of a circular opening, protected by wire-gauze, for the lower portion of the frame. To this opening a flexible tube could be fitted, which was connected with a supply of fresh air: this was to allow of the use of the lamp in the presence of firedamp. Mr. Biram stated that "a good many" had been made.‡

In 1849 a Select Committee of the House of Lords was appointed in Great Britain to enquire into the best means of preventing the occurrence of dangerous accidents in coal-mines. In their Report dated August 1st, 1849, the committee drew attention to the evidence which they had received respecting the safety-lamp, and mentioned the chief objections to Sir Humphry Davy's original invention—namely, defective light, and possible insecurity in a strong explosive current. They alluded particularly to the evidence of Mr. Biram and of Dr. Clanny

* *Annales des Travaux Publics de Belgique, Doc. Adm.*, 1851, vol. x., page 91, plate xii.

† British patent No. 12,489.

‡ *Minutes of Evidence*, Select Committee of the House of Lords appointed to Inquire into the best Means of Preventing the Occurrence of Dangerous Accidents in Coal Mines, 1849, Question No. 1,699.

regarding two recent modifications of the lamp for the purpose of obviating these defects. They declined to express any opinion upon the comparative merits of these inventions, "which can be only decided by practical experience."

An interesting feature of this enquiry was the feeling in favour of the Davy lamp expressed by several important

FIG. 30.—BIRAM LAMP.

Reproduced by permission of the Authorities from a lamp in the collection at the Science Museum, South Kensington.

FIG. 31.—GAUZE LAMP, OR SCOTCH DAVY LAMP.

Reproduced from a lamp lent by Mr. James Barrowman.

witnesses. Scientific men (Sir H. T. de la Beche, Dr. Lyon Playfair, Prof. D. T. Ansted, and John Hutchinson, M.D.), all of whom had some knowledge of the conditions under which the mining of coal was carried on*; mining engineers and managers (Messrs. Nicholas Wood, T. E. Forster, J. T. Barkley, W. Peace,

* Sir Henry T. de la Beche and Dr. Lyon Playfair had reported to the Home Office in 1847 on the gases and explosions in collieries.

Matthias Dunn, and T. J. Taylor); also Mr. John Atkinson, a collier at Jarrow Colliery, Durham, all considered the lamp safe, except in the circumstances foreseen by the inventor, although some of them were more emphatic in their approval than others. Mr. T. J. Taylor quoted a remark made to him by a viewer in the North of England:—

"If their Lordships ask concerning the safety of the Davy lamp, you may state that we have taken off 1,000 acres of pillars during the last thirty years, and used nothing but Davy lamps all that time, without one accident happening."*

Of all the safety-lamps, the Davy seems to have been the one most used, although the Stephenson, with a covering of wire-gauze, was in use in some collieries in the North of England: in some cases the Clanny was preferred on account of the better light given by it;† but there seems still to have been considerable mistrust of lamps in which the flame was not surrounded by gauze. The Mueseler lamp, and the fact that it was in favour in Belgium, was mentioned by several witnesses; but this lamp and the Clanny seem to have been regarded as very similar. Some witnesses mentioned rules which were in use at various collieries on the subject of safety-lamps.

In 1850 an Act of Parliament was passed for the inspection of coal-mines in Great Britain. Among other matters placed under the purview of the Inspectors was the mode of lighting.

The "*Gauze*" *lamp* or "*Scotch Davy*" (Fig. 31)‡ was cylinder-shaped, with a conical top, suggestive of a tall slim haystack; indeed, the lamp in its first and larger form was sometimes named the "Haystack" lamp. With the exception of the portion containing the oil-vessel, a ring at the top and bottom of the cylindrical part, and a hook handle on the side, the lamp was composed entirely of wire gauze. The body of the later and smaller lamp was 2·9 inches in internal diameter and 7 inches high, surmounted by a flattened gauze cone 2 inches high, the gauze of which was doubled for about half its height. It had a flat wick $\frac{5}{8}$ inch broad.

* *Minutes of Evidence*, Select Committee of the House of Lords, 1849, Question No. 6,042.

† Even as late as 1868, M. G. Arnould, in a paper on the safety-lamp in England, stated that the Davy, Stephenson, and Clanny lamps were the only ones in general use; from information supplied to him 60 per cent. of the lamps used appear to have been Davys, 30 per cent. Stephensons, and 10 per cent. Clannys (*Annales des Travaux Publics de Belgique*, 1868, vol. xxvi., page 10).

‡ The writers are indebted to Mr. James Barrowman for this description of the lamp. An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

It is questionable whether the lamp was ever considered a safe lamp in a fiery mine. The desire for a better light than that afforded by the Davy lamp, in circumstances where firedamp in moderate quantities had to be guarded against, seems to have been the occasion of its introduction. Neither the name of the originator nor the date of introduction of the lamp has been ascertained by the writers; but Mr. James Anderson, of Farme Colliery, states that it was in use in the Hamilton district in 1859, and that in 1861 he discarded it at Farme Colliery as unsafe. A firm of makers in Airdrie state that they made the lamp as early as 1850.

The lamp had considerable vogue in collieries where firedamp was not abundant, as a precaution against the incursion of gas from the goaf in the working back of the pillars in pillar-and-room workings.

The lamp fell into discredit after the Blantyre explosion of 1877, but it lingered for at least 10 years more.

The British Royal Commission of 1886* found that this lamp was unsafe if exposed for more than a few seconds to a current of explosive mixture passing at a velocity of 400 feet per minute (6·6 feet per second).

The *Jack lamp*,† brought out in 1850, was a shielded Davy. The Davy gauze was enclosed in a glass cylinder which extended up as far as the short gauze cap placed on the top of the main gauze cylinder, and was supported on the top of the oil-vessel by four metal pegs to allow of admission of air through the lower part of the gauze cylinder.

The *Westphalian lamp* is stated to have been introduced into the Westphalian coalfield about 1850.‡ The lamp was of the Boty type; air entered through holes in the metal ring below the glass, which were unprotected by gauze. A variety of this lamp with air-feed through holes in the ring below the glass protected by a horizontal gauze just below the flame, known as the West-

* *Final Report of the Royal Commission on Accidents in Mines*, 1886, page 75.

† This lamp is called "Jack's" lamp in the "Catalogue of the Collection of Safety-lamps of the North of England Institute of Mining and Mechanical Engineers." A Jack lamp is in the collection of safety-lamps at the Science Museum, South Kensington.

‡ Berginspektor Fälndrich, *Die Entwickelung des Niederrheinisch-Westfälischen Steinkohlen-Bergbaues in der zweiten Hälfte des 19ten Jahrhunderts*, vol. vii., page 222.

phalian lamp with protected perforated inlet-ring (*Westfälische Lampe mit geschütztem Siebring*), was mentioned by the Prussian Firedamp Commission of 1886.* After the researches of that Commission had shown the danger of the unguarded perforated ring on account of the facility with which it passed flame, a solid ring was substituted for the perforated ring, and air was made to enter the lamp from above the flame through the bottom of the gauze cap, as in the Clanny or over air-feed Boty.†

It has already been mentioned that regulations for the Provinces of Hainaut and of Liége had made the use of safety-lamps compulsory in mines containing firedamp, or in certain mines, as early as 1841 and 1844. This provision appears to have been strengthened in Belgium by a "Règlement Général" of March 1st, 1850; and on July 10th, 1851, a "Réglement Provisoire" was published,‡ which directed that the following lamps only should be used in mines containing firedamp (*mines à grisou*):—

(*a*) The Davy of ordinary dimensions and prescribed gauze.

(*b*) 1° The Mueseler, "conformable to drawing No. I."

2° The Mueseler modified by M. Eloin, "conformable to drawing No. IV.," with prescribed gauze.

(*c*) The Boty, "conformable to drawing No. II.," and conditions as to inlet-holes and gauze.

(*d*) The Eloin, "conformable to drawing No. III.," and to certain conditions.

A type lamp of each system was to be deposited in the Department of Public Works and in each mining district. Also gauges and wire-counters (*compte-fils*) were to be at the disposal of the officials of the mines.

A Select Committee on Coal Mines was appointed in Great Britain in 1852. In their Report dated June 22nd of that year the committee regretted that so little attention had been paid to the remarks on the undue confidence that had hitherto been placed in the Davy lamp, and to the suggestions that reliance should

* *Report of the Prussian Sub-Commission on Safety Lamps*, vol. iii., plate 10.

† Berginspektor Fähndrich, *loc. cit.*; and *Report of the Prussian Sub-Commission on Safety-lamps*, vol. iii., page 5.

‡ *Annales des Travaux Publics de Belgique, Doc. Adm.*, 1851, vol. x., page 91. The writers have not attempted a translation of the foreign legal terms. A literal translation would be useless, and an attempt to find a corresponding term in English might be misleading.

chiefly be placed for safety on increased ventilation put forward by the committee of 1835. They concurred in the opinion expressed by the committees of 1835 and 1849, and with that so strongly expressed by the South Shields Committee, that " where a proper degree of ventilation does not exist in a mine, the Davy lamp, or any modification of it, must be considered rather as a lure to danger than as a perfect security." They stated that it was practically safe in a still atmosphere; admirable for exploring, or as an indicator of danger, in the hands of a " cautious overman "; but in a current, as admitted by its illustrious inventor himself, it was not a security: it might in moments of excitement be dangerous in the hands of an ordinary workman.

Allusion was made to experiments on safety-lamps carried out by Dr. Bachhoffner* before the committee at the Polytechnic Institution.

The use of the safety-lamp in fiery mines was recommended until it had been proved that ventilation could be so improved as to free the workings of explosive gas. The insufficient light given by the Davy lamp was noticed, and attention was drawn to the " Reflecting lamp "—a lamp of greater reflecting power with a double gauze.

The following lamps appear to have been brought out between 1850 and 1855:—

*Davy Type.*

*Mr. E. Simons's* lamp† (1852) was a large Davy, with an arrangement for extinguishing the light automatically when the lamp was opened.

Mention was also made of a lamp of *Simons's*‡ used in some mines in England, in which the oil was contained in a ring-shaped oil-vessel at the bottom of the lamp, which was interrupted at one point to admit of the insertion of a glass. The lamp had two cylindrical gauze caps, one inside the other, with a space between the two. The lamp was carried by means of a handle placed at the side.

* Spelt " Bachhoffner " in this Report; " Backhoffner " in the Report of 1854.

† An example of this lamp is in the collection of safety-lamps at the Science Museum, South Kensington.

‡ *Historia, Descripcion y Crítica de los Sistemas Empleados en el Alumbrado de las Excavaciones Subterráneas*, by A. Gil y Maestre & D. de Cortazar, Madrid, 1880.

The "*Reflecting*" lamp mentioned by the Select Committee on Coal Mines (1852) was stated to have been made of polished wire-gauze, instead of black iron-wire, in order to give a reflecting surface. A "polished cone" was placed below the flame, in order to reflect the light and to prevent it from being absorbed by the "oil-can." The lamp was fitted with two gauze cylinders; "the second cylinder is placed at such a distance from the first, that the firedamp enclosed between the cylinders (if the flame passes the first) explodes, and may extinguish itself."*

*Clanny Type.*

*Cooke's lamp*† (1853) had a dioptric lens.

*The Henderson lamp* was similar to the Clanny, but had two concentric glasses, the space between which was filled with water. It weighed 3½ pounds.‡

*Boty Type.*

In the *lamp of Dr. Fife* (also spelt Fyfe) air was admitted below the glass, the inlet being guarded by a disc of gauze. Out-

* *Report from the Select Committee on Coal Mines*, 1852, page xiii.

Some experimental work carried out by Dr. R. V. Wheeler at the testing-station at Eskmeals in 1912 showed that, provided the distance between the point of ignition in the lamp and the gauze was 9 inches or less, the flame of the most explosive mixture of methane and air (about 10 per cent. methane) would not pass through two gauzes, no matter how arranged or whether they were in close contact or separated by any distance up to half an inch. Hence, Dr. Wheeler concluded that "to ensure absolute safety, there should not be a greater distance than nine inches between the wick of a lamp and the top of the gauze chimney."

Under other conditions, however, "flames which do not pass through two gauzes when those gauzes are in close contact may pass through if the gauzes are separated by as little as 0·002 inch." To prevent the passage of flame, Dr. Wheeler considered it necessary for the gauzes to be in close contact ("Experimental Research Work on Safety Lamps," Report by Dr. R. V. Wheeler, *Mines and Quarries: General Report, with Statistics, for 1912*, by the Chief Inspector of Mines, part ii.—Labour, pages 75 and 76).

M. Marsaut found that the addition of a second gauze to large Davys, such as the Davy du Gard and Dubrulle's lamp, diminished the frequency of external explosions, but did not entirely prevent them. In this connexion the principle enunciated by Sir Humphry Davy and confirmed by M. Marsaut should be remembered, namely, that the safety of the lamp is increased by keeping down the cubic contents of the lamp and increasing the area of conducting surface.

It would appear, therefore, that the safety of the "Reflecting" lamp must have depended on its dimensions, and these were not given.

Some experiments on the effect of placing the gauze caps a short distance apart appear to have been made in Germany (*Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, 1900, vol. xlviii., B., page 135).

† An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

‡ *Minutes of Evidence*, Second Report of the Select Committee, 1853, Questions Nos. 2,281 to 2,291; Saxon Commission, 1884.

side the glass was a casing of mica, and above the glass were two gauze caps, one inside the other. The lamp was patented in 1853, and the specification (No. 166) covered also the use of an elastic ring or washer of vulcanized indiarubber interposed between the end of the glass and the metal surface in contact with it, to allow of the expansion and contraction of the glass.

*Eloin Type.*

In the *Thornton* lamp* (1853) the glass was protected by a mica shield.

*Lamps not Referable to the Above-mentioned Types.*

The *lamp of Dr. Glover and Mr. J. Cail** was patented† in in 1852. The flame was surrounded by two concentric glasses held in their places by an upper and an under ring. Air entered through holes in the upper ring, guarded by gauze, passed down the space between the two glasses, and then through another ring of gauze to the flame. To the upper ring, above the glasses, was attached a cap of wire-gauze, called in the patent "an ordinary wire-gauze chimney"; inside this and immediately above the flame "a conical metallic tube" was fixed to prevent any currents from acting on the flame. The lamp, in fact, appears to have been a kind of Mueseler with air-inlet between the two glasses.

The patent included a movable cover to the "ordinary wire-gauze chimney," but the example in the collection at South Kensington does not possess this.

In 1852 *Mr. H. Mackworth,* H.M. Inspector of Mines, invented a lamp* which he described as "one safety-lamp inside another." The exterior portion of the lamp could be either of the Davy, Clanny, or Stephenson type; but in the case of the two first-named lamps the gauze cylinder was doubled at some distance from the top by the addition of a gauze cap which extended about half-way down the gauze cylinder. Inside this case the flame was surrounded by a narrow glass, slightly curved outwards at the centre; this inner glass stood upon a cone of perforated copper or wire-gauze, through which air passed to the flame; the inner glass was surmounted by a short tapering metal cap, held in its place by a gauze diaphragm.

* An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

† No. 262.

The example of this lamp in the Science Museum at South Kensington has its outer case of Clanny form, and between the interior and exterior glasses a reflector is placed on one side. Mr. Mackworth invented the lead rivet for locking lamps.*

In the lamp invented by *Mr. T. Y. Hall* in 1853,† the flame was surrounded by an internal glass chimney of small diameter, shaped somewhat like the chimney of a house-lamp, outside of which was placed first a cylinder of gauze, and then a glass cylinder. The gauze cylinder and exterior glass cylinder were closed at their tops by a brass ring, perforated with holes; above this ring was a short gauze cap. The main supply of air entered the lamp through very fine holes in the ring below the oil-vessel; the products of combustion were discharged by the internal glass cylinder into the short gauze cap, which was placed at the top of the lamp. A further supply of air could be obtained through the holes in the brass ring above the glass cylinder. This supply was controllable.

In 1853 Mr. Nicholas Wood carried out some experiments on safety-lamps at Killingworth Colliery.‡ The apparatus consisted of a wooden box, in which the lamp under examination was rotated through a still atmosphere of explosive mixture, firedamp piped from a blower in the pit being used. The lamps tested were the Davy, Jack lamp, Clanny, Boty, Stephenson, Eloin, Hall's lamp, and the Glover & Cail; each lamp was allowed to attain a dull-red heat, and was then set in motion. None of the lamps passed flame at a lower velocity than 15 feet per second, except a Clanny with a copper gauze; but the duration of each experiment appears to have been very short. The Stephenson lamp did not pass flame, except when the glass was broken, when it failed at about 14½ feet per second; the Eloin in firedamp went out with the slightest motion; Hall's lamp did not pass flame up to 13 feet per second; the Glover & Cail did not pass flame, although the inner glass cracked.

Similar experiments were made about the same time by Mr. Thomas J. Taylor at Wallsend Colliery, natural firedamp being

* *Transactions of the North of England Institute of Mining Engineers*, 1853-1854, vol. ii., second edition, page 51.

† *Ibid.*, 1852-1853, vol. i., second edition, page 323. An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

‡ *Ibid.*, page 301.

used. The apparatus was so arranged as to allow of the lamp under examination being moved backwards and forwards on a slide through a still atmosphere. All the lamps tested—the Davy, Stephenson, Mueseler, Clanny, Glover, Eloin, and Upton & Roberts—went out. The highest velocity mentioned was 12 feet per second.*

From these experiments Nicholas Wood deduced that the Davy would not pass flame in currents up to 10 feet per second, that it was safe in a still atmosphere, but should be carefully withdrawn when red hot. In practice it was desirable that the Davy should be protected with a shield large enough to prevent the wires of the gauze from becoming white hot. The Stephenson and thoroughly shielded Davy were safe so long as the shield was perfect. Such lamps were extinguished in an explosive atmosphere, on account of the restriction of the intake air. In lamps in which glass was the insulating medium, the admission of air to the flame should be so diminished as to prevent firedamp from burning in the lamp. Tops of single wire-gauze, unprotected, were to be avoided.

Another Select Committee was engaged in Great Britain in 1853-1854 in investigating the subject of Accidents in Coal Mines.† In their Report, dated June 26th, 1854, they stated with respect to safety-lamps:—"Your Committee have received various opinions on the security of the Davy lamp, the majority of which are in its favour." They had before them the results of experiments conducted by Messrs. Wood and Elliott‡ on all the safety-lamps which up to that time had been invented. They considered them a better test than those made by Dr. Bachhoffner at the Polytechnic Institution before the Committee of 1852, as they were carried out with the actual gas of a mine, whereas in Dr. Bachhoffner's tests "common street gas was used." The tests would have been more satisfactory if the boxes used had been larger. The Committee's conclusions were as follows:—

* In his evidence before the Select Committee of 1854, Mr. T. J. Taylor put the velocity at 12 to 14 feet per second (see Second Report, Questions Nos. 1,067-1,068).

† *The Select Committee on Accidents in Coal Mines*, appointed May 31st, 1853; reported June 26th, 1854.

‡ Mr. G. Elliott assisted Mr. Wood in his experiments. *Minutes of Evidence*, Report of the Select Committee, 1854, Question No. 827.

"That safety lamps, however valuable, should not be relied upon for the prevention of explosions.

"That the ventilation of mines should be kept so good, that under ordinary circumstances it would be safe to work with naked lights.

"That in fiery mines, especially those which are liable to sudden outbursts of gas, safety-lamps add largely to the security from explosion, and can be used without much, if any, extra cost over the naked light."*

The evidence given in these enquiries, with respect to safety-lamps, did not differ materially from that furnished to the Lords' Committee of 1849; but a good deal of the evidence published in the Third Report of the Committee of 1854 related to rules which were then being drafted for various colliery districts, some of which referred to safety-lamps.

In 1855 the Coal Mines Inspection Act, 1855, came into operation in Great Britain. This Act laid down regulations respecting the appointment of Inspectors of Mines, and defined their powers and duties. Among the subjects on which the Inspectors were to report was included "the mode of lighting or using lights:" the Act contained a number of "General Rules," and provision was made for "Special Rules" to be drawn up for each colliery.

On April 8th, 1858, an "Arrêté Royal" was published in Belgium, one of the articles of which made the employment of safety-lamps permitted by the administration of mines obligatory for collieries which contained firedamp ("les houillères à grisou"). This was followed on April 29th, 1864, by an "Arrêté Ministériel" making the use of the Mueseler safety-lamp obligatory in mines containing firedamp ("mines à grisou").†

The following lamps appear to have been invented towards the close of this period:—

The *Howden & Thresh lamp*‡ (1859) was a large Davy, in which the sides of the oil-vessel were prolonged downwards to form a ring, which was pierced with holes, thus forming an air-chamber below the bottom of the oil-vessel. Air for combustion entered through these holes, passed through two horizontal gauze diaphragms placed below the bottom of the oil-vessel, and was conducted near to the level of the wick through a tube passing through the oil-vessel.

* *Fourth Report*, 1854, page 5.

† *Annales des Travaux Publics de Belgique*, 1873, vol. xxxi., page 306; and 1876, vol. xxxiv., page 368.

‡ An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

*Peter Bourne's lamp** (1862) was a Davy fitted with a self-extinguishng arrangement to prevent the lamp from being opened.

The *Laurent-Lermusiaux* was an unshielded Davy with a pneumatic lock.†

In a form of unshielded Davy used in Westphalia a gauze-cap of larger diameter than Davy's was used, which was made slightly conical, the smaller end being uppermost: on the top of this coned gauze-cap was a short cylinder of gauze.‡

The *Tin-can Davy* or *Davy in a case* (Fig. 32, page 634)* was introduced about 1865. It consisted of a Davy enclosed in a tin-casing. Air was admitted through holes in the tin-casing below the flame. In one form the light shone through glass placed like a window on one side of the casing only; in another form the glass completely surrounded the flame, the tin-casing being cut away at that point. The flame was, of course, surrounded by the Davy gauze.

The British Royal Commission of 1886 found that this lamp resisted currents of explosive mixture up to a velocity of 2,000 feet per minute.

*Evans's lamp* (1861)* was of the Stephenson type, but had two glasses, the outer one cylindrical, the inner one contracted into a chimney above the flame; both glasses were surmounted by a cone of wire-gauze. There was no external covering of wire-gauze.

The *Saarbrücken lamp* was of the Boty type, with a slightly conical gauze cap, on the top of which was a shallow copper cap pierced with fine holes.§ Air was admitted above the flame through the bottom of the gauze cap.

In the lamp of *William Wilkins* (1858)‖ air entered through holes in a flange below the oil-vessel, and passed to the flame through tubes in the oil-vessel guarded with gauze. The lamp had two gauze caps above the glass, and was fitted with a small metal chimney, which descended as far as the apex of the flame

* An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

† *Des Lampes de Sûreté dans les Mines de Houille. Lampe de M. Laurent Lermusiaux à Ouverture Pneumatique*, by A. Prouteaux, Paris, 1861.

‡ *Die Entwickelung*, etc., vol. vii., page 226, fig. 160.

§ *Ibid.*, page 223, fig. 156.

‖ 1858, Patent No. 1,398; Saxon Commission, 1884.

and was held in its place above the glass by a metal disc. A glass "of lenticular form" was used.

The lamp of Eckhardt* resembled the Boty externally, but contained an internal cylinder of glass around the flame; this cylinder narrowed down above the flame, and extended high up into the gauze. Air entered the lamp through the gauze cap, and passed down the space between the external and internal glass cylinders to the top of the oil-vessel, whence it was conducted by tubes through the oil-vessel into a chamber at the bottom of the oil-vessel; another set of tubes conveyed the air to the flame through the oil-vessel, and the products of combustion rose up through the inner glass cylinder and passed out through the top of the Boty gauze cap.

## XII.—Period 1867 to 1879.

During this period several investigations relative to the safety-lamp were conducted, the most important being those of the North of England Institute of Mining and Mechanical Engineers; of the Belgian Government; of the Société de l'Industrie Minérale in France; and of Messrs. Smethurst & Ashworth in 1878. The experiments conducted by the North of England Institute appear to have attracted widespread attention, and were probably those mentioned in the Report of the Belgian Commission of 1867-1873. A Belgian engineer, M. G. Arnould, visited the North of England coalfield in 1868, bringing with him a "Belgian-type" Mueseler, which he tested at Pelton Colliery. He found that this lamp, which was in good condition and had been given to him by the inventor himself, "the late M. Mueseler," would pass flame in a current of explosive mixture moving at a velocity of 2·44 metres (8 feet) per second, when it was inclined towards the current; the same lamp in a vertical position passed flame at a velocity of 5 metres (16½ feet) per second. M. Arnould embodied his experiences in a very interesting paper,† to which was appended a translation of the Report of the North of England Institute. He mentioned also

* *Zeitschrift für das Berg-. Hütten,-und Salinenwesen im preussischen Staate*, 1869, vol. xvii., page 85, plate ix., figs. 20 and 21; Saxon Commission, 1884.

† "Rapport sur le Résultat des Expériences faites en Angleterre sur les Lampes de Sûreté," by M. G. Arnould, Ingénieur des Mines, *Annales des Travaux Publics de Belgique*, 1868, vol. xxvi., page 1.

tests conducted at Barnsley and at Pelton Colliery, and that he was able to take part in the last-named.

The only new type of lamp introduced was the Gray; but attempts were made to improve most of the existing types. Great attention was paid to the Mueseler: as might be expected, this was particularly the case in Belgium, in which country the confidence felt in that lamp was reaffirmed by an "Arrêté Royal" in 1876; but the example of the Belgian mining authorities could not fail to make an impression in other countries also, and consequently both in France and in Great Britain this lamp (or modifications of it) appears to have attracted more notice than was previously the case. Although the alterations made in the lamp appear in the first instance to have been due simply to a desire to eliminate those points in which the lamp was not quite satisfactory, yet in some cases they brought about a complete change in the behaviour of the lamp. For example, M. Marsaut, in his experiments in the Marsaut bell, found that the "Belgian-type" Mueseler was liable to internal explosion; on the other hand, the lamp of M. Arnould and M. Godin, in which the Mueseler chimney was continued downwards by a truncated cone of glass, and the Evan Thomas of similar type, suppressed the phenomenon of internal explosion altogether.*

Some of the lamps brought out in this period and in the next sought to attain a high degree of safety by complexity of construction. Present experience seems to show that this is not only undesirable, but unnecessary: this, however, is probably due to the use of the bonnet, the value of which, during the period under review, does not appear to have been generally recognized.

The tendency of legislation in Belgium still continued in favour of the use of the Mueseler lamp, although certain other lamps were admitted for various purposes by the "Arrêté Royal" of 1876. In Great Britain the Act of 1872 required the use of locked safety-lamps for certain specified purposes and under certain conditions, but no regulations were laid down as to the type of lamp to be employed.

During this period various proposals were put forward for improving the light given, for preventing the opening of lamps in the pit, and for locking lamps.

*"Étude sur la Lampe de Sûreté des Mineurs," by J. B. Marsaut, *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 321.

The lamps of the Protector Lamp & Lighting Company were constructed to burn colzaline, a refined mineral oil, and were fitted with the Protector device* for preventing the lamps from being opened after they had been lighted and put together. In the Canevaile lamp† petroleum was used as the illuminant. Among devices for locking, Craig and Bidder's‡ magnetic lock brought out in 1869 may be mentioned, and the magnetic locks of M. Williers of St. Étienne, and of M. Chauselle.†

In 1874 Mr. W. E. Teale patented an arrangement for lighting lamps by electricity by passing the current through fine platinum points.

In 1867 the North of England Institute of Mining and Mechanical Engineers appointed a committee to conduct tests on safety-lamps, and the reports of the committee were published in the *Transactions* of the Institute.§

Two enquiries were conducted, one to ascertain the effect of oily or greasy gauzes, the other on the velocity of inflammable mixture which would cause explosion. The experiments as to velocity were carried out in two series, one in which the lamps were rotated in a box in a still atmosphere, the other in which the lamps were exposed in a covered trough to a current of explosive mixture.

In the first series, which was carried out at Hetton Colliery, coal-gas is stated to have been used, but some experiments appear to have been made in firedamp. It was, however, pointed out that the conditions were not exactly those to which safety-lamps were usually subjected, and that the formation of carbonic-acid gas in the box rendered it impossible to know what was the composition of the atmosphere in the box at the time of explosion. Under these conditions the lowest velocity at which the Davy caused explosion when rotated was 13 feet per second.

* An illustration of this was given in the *Final Report of the British Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 36.

† *Historia, Descripcion, y Crítica de los Sistemas Empleados en el Alumbrado de las Excavaciones Subterráneas*, by A. Gil y Maestre & D. de Cortazar, Madrid, 1880. In the same book were mentioned a screw-lock of M. Aillot, lead rivet of M. Arnould, and a soldering arrangement of M. Dinan; also the contrivance of M. Olanier of St. Étienne and of Herr Hernbeck, an Austrian, to secure the extinction of the light when the bottom of the lamp was unscrewed.

‡ *Transactions of the North of England Institute of Mining and Mechanical Engineers*, 1869-1870, vol. xix., page 15.

§ *Ibid.*, 1867-1868, vol. xvii., pages 2-19 and 37-40.

The second series (the tests in the covered trough) was carried out at Eppleton Colliery, firedamp from the pit being used. It was shown that a Davy lamp was unable to resist an explosive mixture of firedamp and air moving against it with a velocity of 8 feet per second. The addition of an ordinary shield to the Davy was of little use; a complete shield afforded some little protection, but flame passed at a velocity of 12 feet per second. The Clanny and Stephenson lamps passed flame in an explosive mixture moving at a velocity of 9 feet per second, and a Mueseler* lamp passed flame as easily as the Davy with a velocity of explosive mixture of 8 feet per second.

Later on, an apparatus appears to have been erected by Mr. Lindsay Wood† at Hetton Colliery, in which the velocity of explosive mixture could be increased to 35 feet per second, and the following lamps were reported as being safe:—the Lindsay Wood (a modified Clanny); Mr. D. P. Morison's lamps (a modified Stephenson, and a modified Glover & Cail); Mr. John Daglish's lamp (a Davy in a case); Mr. P. B. Flood's lamp (a modified Clanny); and a lamp invented by Messrs. Ritson & Bell, of Pelton Colliery.

The lamps tested in these various experiments appear to have been the "Common" Davy without a shield; the Davy with a shield 2 inches long; the Davy with a shield reaching to the top of the gauze; the Clanny; the Stephenson; the Mueseler; the Eloin; the Macrae; the Lindsay Wood; the Higgs;‡ the D.P. Morison: the J. Daglish; the P. B. Flood; the Ritson & Bell; the Glover & Cail; and the Sharp & Young.

Mention was also made about the same time of tests on safety-lamps at Pelton Colliery, and of some tests made at Barnsley.§

The British Committee on Mines, which reported on July 31st, 1867, does not appear to have tested any lamps, nor to have taken cognizance of the relative safety of various types of lamp.

* MM. Watteyne and Stassart (*Annales des Mines de Belgique*, 1904, vol. ix., page 951) described this Mueseler as being "à cheminée large." They quoted a paper by M. G. Arnould (*Annales des Travaux Publics de Belgique*, 1868, vol. xxvi., page 1), in which M. Arnould mentioned Mueseler lamps tested at Barnsley and at Pelton, the chimney of which differed greatly in its dimensions from that of the "Belgian-type" Mueseler; these lamps, which caused explosion as easily as the Davy, M. Arnould called "la lampe anglaise dite Belge Mueseler."

† Now Sir Lindsay Wood, Bart.

‡ This was apparently any sort of safety-lamp enclosed in a casing partly of glass and partly of gauze. Patent No. 2230, 1867.

§ M. G. Arnould, *Annales des Travaux Publics de Belgique*, 1868, vol. xxvi., page 13.

Regulations as to the examination and locking of safety-lamps were suggested.

The importance, however, of safety-lamps was recognized in the Coal Mines Regulation Act of 1872, which required inspection with a safety-lamp in mines in which inflammable gas had been found within the previous twelve months, and with a locked

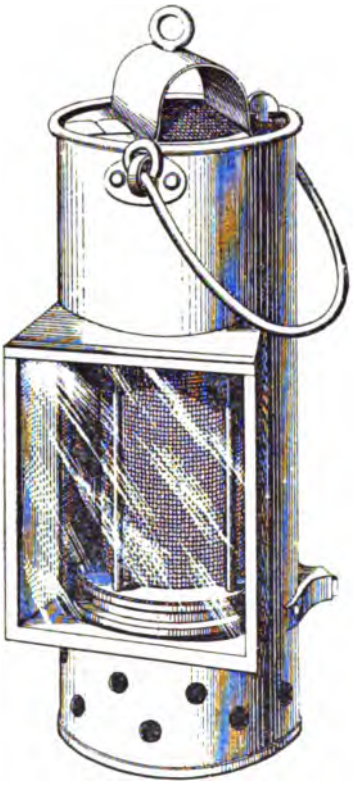

Fig. 32.—Tin-can Davy Lamp.

Fig. 33.—Gray Lamp.

Figs. 32 and 33 are reproduced, by permission of the Controller of H.M. Stationery Office, from the Final Report of the Royal Commission on Accidents in Mines, 1886, appendix xxiv., figs. 3 and 17.

safety-lamp in case of the withdrawal of men owing to the presence of noxious gas. Locked safety-lamps only were to be used in workings approaching a place in which there was likely to be an accumulation of explosive gas. Wherever safety-lamps were required to be used by the Act, or by the Special Rules made in pursuance of the Act, the lamps were to be examined by a com-

petent person, in order to ascertain that they were secure and securely locked.

In 1867 or 1868, in France the Société de l'Industrie Minérale appointed a Commission, which presumably is the one alluded to by subsequent writers as the "Commission de St. Étienne," to carry out experiments on safety-lamps.* These were made in an apparatus of the covered-trough type, the current being produced by a fan; lighting-gas was used, and tests could be made in horizontal or in inclined currents. Experiments were also conducted in a still explosive atmosphere in a box, and photometric tests were made.

The first tests were made on a Davy and a St. Étienne lamp. From these the Commission deduced that the lamps actually in use at St. Étienne would pass flame in an explosive current of 1·7 metres (5½ feet) per second, and would stop the passage of flame when the velocity did not exceed 1·20 metres (nearly 4 feet) per second, also that the limit of the Davy was 7 to 7½ feet per second. In a current, gauze cylinders of large diameter allowed flame to pass through less easily than cylinders of small diameter,† other things being equal. In the explosive mixture which most easily caused the flame to pass through the gauze, the proportion of gas was less than that which gave the maximum explosion.

Lamps in which the flame was surrounded by glass were divided into "over-feed" ("alimentation par le haut") and "under-feed" ("alimentation par le bas") types.

Of the former class some lamps of the Clanny type were tested; with one gauze, such lamps filled with flame at a velocity of 3·5 metres (11½ feet) per second, and passed flame in one or two seconds; with two gauzes, flame passed at the same velocity. The Mueseler lamp did not pass flame in a current of explosive mixture moving at a velocity of 4 metres (13 feet) per second; but the opinion was expressed that at higher velocities the lamp would pass flame, as had been proved by experiments in England. Nevertheless, the Commission considered the Mueseler lamp to

* *Bulletin de la Société de l'Industrie Minérale*, 1867-1868, series 1, vol. xiii., page 723; "Expériences sur les Lampes de Sûreté: Rapport de la Commission désignée par le Conseil de l'Administration de la Société de l'Industrie Minérale."

† The fact that this conclusion was directly opposed to that reached by Sir Humphry Davy and Dr. Bischoff was mentioned in a footnote to the Report. The Commission's conclusion has not, however, been upheld by subsequent investigations.

be safe in currents of the velocity ordinarily used in mines. As the result of their experiences, the Commissioners put forward a lamp of this type of their own design—"Modèle A."

The lamps of the under-feed type tested were the Upton & Roberts, the Dumesnil, and the Combes. The two former were found to be easily extinguished when agitated or moved quickly; the latter was unsafe in an explosive current exceeding 13 feet (4 metres) per second. The Commission designed a lamp of this type—"Modèle B."

The Morison lamp was also tested, but was considered to require further modification.

Among other suggestions the Report advocated the use of a shield (*écran*) to prevent the flame from being projected against the gauze, and suggested that in glass lamps the air should enter above the glass. Lamps fitted with a simple cylinder of metallic gauze were unsafe in currents of a velocity likely to occur in coal-mines. The Mueseler and the Commission's "A" and "B" lamps were reported to be the best.

*Lamp Modèle "A"* of the St. Étienne Commission (1867-1868) was a modified Mueseler with a cylindrical shield above the glass; a short distance below the top of this shield rectangular openings were cut in the shield through which air entered. The air descended to the flame through the usual gauze diaphragm, which supported a cylindrical chimney, the lower end of which projected very slightly below the diaphragm. The products of combustion returned up this chimney, which terminated at its upper end in a gauze cap. Just below the commencement of this cap an annular flange projected from the outer shield to the chimney, so as to prevent the fresh air which entered through the rectangular openings in the shield from passing upwards.*

*Lamp Modèle "B"* of the St. Étienne Commission was a modified Mueseler, similar in all respects to Modèle "A," except that, in addition to the air-feed from above the flame, air entered through guarded inlet-holes in the ring below the glass.

On April 16th, 1867, a Commission was appointed by the Belgian Government to make experiments and to ascertain whether safety-lamps fed with petroleum could be used in fiery mines.

* *Bulletin de la Société de l'Industrie Minérale*, 1867-1868, series 1, vol. xiii., page 723.

On January 20th, 1868, in consequence of experiments made in England on the behaviour of safety-lamps in currents of explosive mixture passing at a high velocity, the sphere of the Commission was enlarged so as to include the behaviour of all kinds of safety-lamps under these conditions.

The testing apparatus was of the trough type, lighting-gas being employed. The current was produced by a fan, the usual velocity being 6 metres (20 feet) per second.

The tests included a continued exposure of the lamps to the current of explosive mixture for 5 to 6 minutes; the behaviour of the Mueseler lamp with powdered coal-dust and oil on its horizontal gauze; the effect on the lamps of oscillation in a current of explosive mixture; of inclined currents, ascending or descending; and of variation in the quantity of gas contained in the current.

The whole of the experiments proved that no means of lighting could be considered absolutely safe. So far as the Davy and the "Porion" (a species of Boty) lamps were concerned, it was known from the commencement that they were unsafe in an explosive current travelling at 2·25 metres (7½ feet) per second; besides, the "Commission de St. Étienne" had already ascertained that they ceased to be safe in a current of explosive mixture of a velocity of 1·7 metres (5½ feet) per second.

The Mueseler lamp, both the "type" lamp,* and other patterns, behaved well. Nevertheless, this lamp had in several cases produced explosions of which the actual cause was not known. Variation of the quantity of gas passing, greasing of the horizontal gauze, swinging, and whirling ascensional currents were found to produce explosion.

In the experiments on lamps inclined at an angle to the vertical, up to 30 degrees, the Commission used a holder in which the lamps tested were placed; the eddies thus set up appear to have tried the lamps severely, since the Report mentioned "les effets désastreux des expériences de ce genre, auxquelles aucune lampe n'a résisté."†

Of the types derived from the Mueseler the Godin "G" and the Joassin had resisted nearly all the experiments, the last-named being the best.

* The "type" lamp was the lamp the proportions of which had been prescribed by the Belgian Government.

† Report, page 310.

It was recognized that the safety of the Mueseler lamp rested above all in the narrowness of the upper part of the chimney and in the proportions of the various parts. The Commission appears to have reported in 1873.*

The result of the Report of the Commission was an " Arrêté Royal " of June 17th, 1876, by which the employment of the " Mueseler type " lamp, fed with vegetable oil, " conformable to drawing No. 1," was made obligatory for the lighting of fiery mines (" mines à grisou "). The Mueseler-Godin, Mueselers of larger than standard size, and Porion lamps (with double gauzes) were allowed to be used for specified purposes, or in certain places, or by certain persons. A type lamp of each of the systems allowed or tolerated was deposited in the Department of Public Works, also in each district of mines.†

The following lamps were brought out during this period :—

*Davy Type.*

*Mr. John Daglish's lamp*‡ was a Davy enclosed in a case.

The *lamp of P. Adie & W. Simpson* (1870)§ was a large Davy fitted with a self-extinguishing arrangement. It burned paraffin, and had a glass chimney inside the gauze.

A form of shielded Davy was invented by *Mr. A. L. Steavenson* in 1877.§

The *Dinant lamp* was a Davy with a special closing arrangement and a slightly conical gauze.‖

*Stephenson Type.*

The *Williamson*¶§ *lamp*, patented in 1878, may be described as a Stephenson inside a Clanny. The main air-inlet was

*Annales des Travaux Publics de Belgique*, 1873, vol. xxxi., pages 306-351. A translation of this Report was given in the *Transactions of the North of England Institute of Mining and Mechanical Engineers*, 1879-1880, vol. xxix., page 113. See also a paper by Mr. A. H. Stokes, *Transactions of the Chesterfield and Midland Institute*, 1877-1878, vol. v., page 54; and " Étude sur les Lampes de Sûreté," by Em. Harzé, *Annales des Mines de Belgique*, 1906, vol. xi., page 58.

† *Annales des Travaux Publics de Belgique*, 1876, vol. xxxiv., page 367.

‡ *Transactions of the North of England Institute of Mining Engineers*, 1867-1868, vol. xvii., page 38.

§ An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

‖ A. Habets, *Revue Universelle des Mines*, 1877, series 2, vol. i., page 115.

¶ *Final Report of the Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 10.

beneath the two glasses, supplemented by air which passed through the Clanny gauze. The top of the main gauze of the Clanny case was covered by a cylindrical shield and a flat dome, from which the products of combustion escaped through holes.

*Clanny Type.*

In 1867 *Mr. Lindsay Wood** introduced a modified Clanny lamp, in which the flame was surrounded by a short cone or cylinder of safety-gauze, which reached only to a short distance below the top of the glass cylinder of the lamp. This lamp was commended by the Lamp-testing Committee of the North of England Institute.

Mr. *P. B. Flood's lamp* (1867)* was a modified Clanny, the gauze being protected by a metal cylinder.

The *Pe'ton*†‡ *lamp*, introduced in 1867 by Messrs. Ritson & Bell, of Pelton Colliery, was of the Clanny type. Inside the Clanny gauze were two metal shields, the outer perforated with small holes, the inner corrugated vertically. The lamp had two concentric glasses around the flame, the space between them not being used. Air entered the lamp through the Clanny gauze, passed through the small holes in the outer shield, and down through the spaces formed by the corrugations in the inner shield. The products of combustion flowed upwards in the inside of the central shield, and out through the top of the Clanny gauze and the superposed smoke gauze-cap.

The lamp of *M. A. Simon* (1870)‡ was a Clanny, with an arrangement for extinguishing the light when the lamp was opened.

*Yates's safety-lamp* (1873) had a lens and reflector in place of the Clanny glass. It was fitted with a self-extinguishing arrangement so as to prevent the lamp from being opened.

*Boty Type.*

The lamp‡ patented in 1868 by *Messrs. W. & F. Hann*, of Hetton, is described in the South Kensington collection as being of the Boty type. Air entered below the glass, and the

* *Transactions of the North of England Institute of Mining Engineers*, 1867-1868, vol. xvii., pages 37-38.

† *Final Report of the Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 23.

‡ An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

gauze cap was replaced by a metal cylinder with a gauze top. The Saxon Commission (1884) mentioned an improved Clanny by Mr. Hann, which was tested at Eppleton.

The *Bainbridge lamp* (1873)*§ had a long conical glass and a short, slightly conical, gauze cap. Air was supplied to the flame through small holes in the ring below the glass. When used without a shield to the gauze, the lamp was practically a Boty; in some forms of Bainbridge lamp, however, the gauze was protected by an external shield, and these were referred by the British Royal Commission of 1886 to the Eloin type.

Various forms of the *Porion lamp* were mentioned in the Report of the Belgian Commission, 1867-1873,† although it is probable that they were in use before this time. They appear to have belonged to the type of Boty, in which air entered through the gauze cap from above the flame. The Porion lamp of Charleroi was described as having one gauze cap, that of Mons two gauze caps; while the Mueseler of Liége was stated to have been a Mueseler without a chimney.

### *Eloin Type.*

The *Gray lamp*‡§ (Fig. 33) was invented in 1868 by Mr. T. Gray, Assistant Inspector of Mines. The air was brought down from the top of the lamp by four tubes (external to the lamp) to an annular chamber below the glass, the inner wall of the chamber being formed by a cylindrical strip of wire-gauze. The products of combustion passed out through a metal tube with a gauze diaphragm at its upper end, which was covered by a dome, perforated with outlet holes. In the patent (No. 3,160) a short conical tube was shown, placed at the bottom of the Eloin tube on the top of the glass.

This lamp was one of the four selected by the British Royal Commission of 1886 for special mention, but it was pointed out that certain improvements could be made.

* *Final Report of the British Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 13.

† *Annales des Travaux Publics de Belgique*, 1873, vol. xxxi., page 306, plate vii., fig. 2.

‡ The Gray lamp was classed by the Royal Commission on Accidents in Mines (1879-1886), in their final report, as belonging to the Eloin type. The method of giving access of air to the inlet-holes differed greatly, however, in the two lamps.

§ An example of this lamp is in the collection of safety-lamps at the Science Museum, South Kensington.

*Laudau's safety-lamp* (1874)* had its air-inlet in the bottom of the lamp through channels passing through the oil-vessel, protected above by a gauze diaphragm. The flame was encircled by a glass cylinder surmounted by a cylindrical gauze cap closely surrounded by a metal tube, which was pierced with holes near its upper end. These outlet holes could be closed at will by means of a sliding ring of some depth. The lamp had a special form of lock, with a self-extinguishing arrangement to prevent the lamp from being opened.

In the *Howat lamp* (1879)†¶ air entered through sixteen small tubes and a gauze ring. In place of the Eloin tube, there were nine small tubes, which delivered the products of combustion to a gauze dome situated below the upper plate of the lamp. The *Howat No.* 5‡ *lamp* was a further modification, in which the inlet-tubes were taken from the bottom of the lamp, and a single, slightly conical, chimney or tube discharged the products of combustion into a gauze-covered box placed on the top of it.

In the *Purdy lamp* (1879)§¶ the glass cylinder was surmounted by a slightly conical metal chimney, which was terminated at the top by a cap of perforated copper, covered by a short gauze cap. Outside this chimney, and of the same size as the outer diameter of the glass, was a cylindrical brass shield with holes cut in it just above the glass and also at the top. The supply of air for the flame entered through small holes and a gauze ring below the glass, but air could also enter through the holes in the bottom of the shield to cool the chimney.

### *Mueseler Type.*

During this period a number of modifications of the Mueseler lamp‖ were brought out, chiefly in Belgium, the objects of the

* *Transactions of the South Staffordshire and East Worcestershire Institute*, 1876, new series, vol. ii., page 65; *Bulletin de la Société de l'Industrie Minérale*, 1879, series 2, vol. viii., page 847; and M. A. Habets, *Revue Universelle des Mines*, 1877, series 2, vol. i., page 115.

† *Final Report of the British Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 14.

‡ *Ibid.*, fig. 15.

§ *Ibid.*, fig. 12.

‖ These are also mentioned in "Étude sur les Lampes de Sûreté," by Fm. Harzé, *Annales des Mines de Belgique*, 1906, vol. xi., page 58.

¶ An example of this lamp is in the collection of safety-lamps at the Science Museum, South Kensington.

alterations being apparently either to prevent gas from burning inside the lamp beneath the gauze diaphragm, or to avoid the inconvenience arising from the rapid extinction of the flame when the lamp was tilted. All these lamps were unbonneted.

The *Mueseler-Thonard** *lamp* was an ordinary Belgian Mueseler fitted with a truncated metal cone which rose for a short distance above the horizontal gauze diaphragm.

The *Mueseler-Joassin No. 1 lamp*†* had a gauze cone, placed over the horizontal gauze diaphragm, which extended to the chimney about half-way up its length. The top of the chimney was of small diameter. The lamp was especially recommended for dusty places.

The *Mueseler-Demanet lamp*‡* had a gauze cone beneath the horizontal gauze diaphragm, extending to the base of the chimney.

In another form of this lamp the chimney was closed by a copper cylinder pierced with slightly conical holes, in order to prevent flame from passing from the interior of the lamp into the gauze cap through the chimney.

The *Mueseler-Joassin No. 2 lamp*‡* had two truncated cones of gauze, one above and one below the horizontal gauze diaphragm. The chimney, as in No. 1, was of small diameter. In some forms of this lamp the upper extremity of the chimney terminated in small outlet tubes, for the same reason as in the Demanet lamp.

In the *Mueseler-Godin G lamp*†‡* (apparently the Mueseler-Godin No. 2 of M. Habets) the chimney was continued downwards by a cone of gauze, which increased the safety of the lamp at the expense of its light.

The *Mueseler-Arnould No. 1 lamp** had a chimney formed of two truncated cones joined together at their smallest diameter at the gauze diaphragm. The upper end of the chimney was closed by a disc of gauze placed a little below the top.

* "Lampes de Sûreté pour les Mines. Travaux de la Commission institutée par Arrêté Ministériel du 20 Janvier, 1868," *Annales des Travaux Publics de Belgique*, 1873, vol. xxxi., pages 306-351.

† "Exposition Internationale de Paris 1878: Exploitation des Mines," by M. A. Habets, *Revue Universelle des Mines*, 1880, series 2, vol. viii., page 299.

‡ "Exposition d'Hygiène et de Sauvetage de 1876, à Bruxelles. Exploitation des Mines, Moyens de Prévenir les Explosions de Grisou et d'un conjurer les Effets," by M. A. Habets, *Revue Universelle des Mines*, 1877, series 2, vol. i., page 115.

The *Mueseler-Arnould No. 2 lamp** had a Mueseler chimney penetrating an inverted truncated cone, as in No. 1.

In the *Mueseler-Godin H lamp** the gauze cap was replaced by a metal cylinder, closed at the top by a disc of gauze. In the lower part of the cylinder just above the glass a strip of gauze was inserted through which air entered the lamp. Between this strip of gauze and the chimney was a deflector arrangement, so contrived that the air had to pass through two horizontal gauzes before it reached the flame.

In the *Mueseler-Godin C lamp*†* (presumably the Mueseler-Godin No. 3 of M. Habets) the Mueseler chimney was continued downwards by a truncated cone of glass, the lower end of which rested on a truncated cone of gauze, through which air entered to feed the flame.

In the *Mueseler-Godin D*†‡* (the Mueseler Godin No. 1 of M. Habets) the lower cone of gauze, on which the glass of the C lamp of this type rested, was absent, its place being taken by supports to hold the inner glass cone, and to allow of access of air to the flame.

In the *Mueseler-Harmegnies No. 5** a metal cone was placed below the diaphragm, and joined to the lower extension of the chimney; on one side of this cone there was an opening through which air was conducted to the wick through a flattened tube.

In the *Mueseler-Harmegnies No. 6** the horizontal gauze diaphragm was replaced by a metal diaphragm, fitted with an opening at one side and a flattened tube or air-conduit to conduct air on to the wick. Between the ordinary exterior gauze cylinder and the chimney was a long gauze cone, which rested on the top of the glass and extended to the chimney.

The *Morisson-Arnould** was a double-glass lamp. The upper part of the lamp was covered by a cylindrical gauze cap of the same diameter as the outer glass cylinder, on which it rested. Air entered through the lower part of the gauze cylinder, and passed to the flame through the space between the inner and

* "Lampes de Sûreté pour les Mines. Travaux de la Commission institutée par Arrêté Ministériel du 20 Janvier, 1868," *Annales des Travaux Publics de Belgique*, 1873, vol. xxxi., pages 306-351.

† "Exposition Internationale de Paris, 1878: Exploitation des Mines," by M. A. Habets, *Revue Universelle des Mines*, 1880, series 2, vol. viii., page 299.

‡ "Exposition d'Hygiène et de Sauvetage de 1876 à Bruxelles," by M. A. Habets, *Revue Universelle des Mines*, 1877, series 2, vol. i., page 115.

outer glasses; this space was guarded at the top by a horizontal strip of gauze and at the bottom by a vertical strip of gauze. Rising from the top of the interior glass was a chimney which widened upwards, until it met the gauze cylinder near to its top; this chimney was closed near its upper extremity by a disc of gauze.

Other modifications of the Mueseler lamp were the lamps of *Liége** and of *Hainaut*.* The *Dubrulle**‖ had an urn-shaped oil-vessel and a short wide chimney.

In the *Mueseler-Godin-Arnould*‡§ the chimney was continued downwards by a truncated cone of glass, which rested on a truncated cone of gauze, through which the feed-air entered. This allowed of the lamp being inclined without being extinguished.

The *Souheur lamp*§ was an unbonneted Mueseler burning mineral oil ("alimentée à pétrole"), with a metal ring round the lower part of the gauze; it was fitted with a special lock with a piston and spring. One form of this lamp had two glasses belled out in the centre, the admission of air being from below the flame. The space between the glasses was not utilized.

The *Goffin lamp*§ was similar to the Demanet, with a second diaphragm bent downwards below the ordinary diaphragm; the wick was raised to improve the light, and there was a special closing arrangement so as to ensure extinction of the light when the lamp was opened. The chimney appears to have been made of gauze.

The *Hislaire lamp*†§ was an unbonneted Mueseler with a glass of curious shape; it was coned inwards from the bottom to about half-way up, at which point it was belled sharply outwards to its full diameter, the object being to allow of the lamp being tilted without being extinguished. The chimney, which

* Belgian Commission, *Annales des Travaux Publics de Belgique*, 1873, vol. xxxi., pages 306-351.

† M. Rossigneux, *Bulletin de la Société de l'Industrie Minérale*, 1879, series 2, vol. viii., page 847, in which "Hislaire" is spelt "Hislain."

‡ M. A. Habets, *Revue Universelle des Mines*, 1880, series 2, vol. viii., page 299.

§ M. A. Habets, *ibid.*, 1877, series 2, vol. i., page 115.

‖ An example of this lamp is in the collection of safety-lamps at the Science Museum, South Kensington. A form of it, intended for pit-bottoms, is shown in M. Marsaut's paper in the *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 321.

appears to have been made of gauze, commenced at the point where the widening of the glass took place.

The *Goebel lamp** had an outer cylindrical gauze, and an inner gauze cap, or chimney of gauze, the upper end of which terminated in a truncated metal cone. It had a double glass, and both over and under air-feed. The upper air-feed took place through the lower part of the gauze cylinder and gauze chimney; the lower air-feed through the lowest part of the oil-vessel. These alterations were so designed as to prevent the burning of gas below the gauze diaphragm and to allow of the lamp being tilted.

The *Marka lamp* and the *lamp of Bay and Thys*† were Mueseler lamps specially designed for the use of surveyors, so that the light could be thrown both sideways and downwards. In the former the oil-vessel formed a ring below the gauze, the lower part of the lamp consisting of an elliptical glass. In the latter the oil-vessel was also ring-shaped, but was rather deeper; it was placed below the glass; the bottom of the lamp below the oil-vessel was of glass.

The *Mozart*‡ was a German lamp of Mueseler type, with a very short and wide chimney.

In *Teale's Mueseler* (1879)§ the space between the chimney and the gauze cap above the diaphragm was filled with non-combustible bodies of globular form.

In one of *Evan Thomas's*‖ lamps air was derived from the top of the lamp through a space formed between two concentric shields, the outer one vertical, the inner one forming a truncated cone with the smaller end downwards; the chimney fitted into the smaller end of this inner shield, and the bases of both rested on the top of the inner glass. From this space the air passed through a gauze diaphragm, and then into a space between two glasses, the inner one of which was not cylindrical, but was belled out slightly in the centre; this glass rested on a vertical

* M. A. Habets, *Revue Universelle des Mines*, 1877, series 2, vol. i., page 115.

† M. Rossigneux, *ibid.*, page 860; also paper by M. Perrin in the same volume, page 774.

‡ G. Arnould, *Annales des Travaux Publics de Belgique*, 1868, vol. xxvi., page 14.

§ *Transactions of the Chesterfield and Midland Institute*, 1880-1881, vol. viii., page 288.

‖ *Final Report of the Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 18; Saxon Commission, 1884; M. Marsaut's paper, "Étude sur la Lampe de Surêté des Mineurs," *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 321.

ring of gauze, through which air passed to the flame. The products of combustion rose up through the inner glass and chimney, through a disc of gauze which closed the top of the inner shield, and passed out through openings in a dome which practically closed the top of the outer shield.

The lamp of *Mr. D. P. Morison** was patented in 1867. It was unbonneted, and had two concentric glasses. Air entered through a horizontal strip of gauze placed at the top of the space between the two glasses, passed downwards through this space, and through a horizontal strip of gauze to the flame. Above the inner glass cylinder was a gauze cylinder, inside of which was a metal chimney, the lower end of which rested on the inner glass cylinder; this chimney was coned sharply inwards for a short distance, and then widened out gradually, until at the top it was of the same diameter as the gauze cylinder; it was closed near the top by a disc of gauze.

The patent (No. 1938) covered an alternative form of lamp in which the air-feed was from below the flame through perforations in a metal ring, over which a shield was fitted externally. "In this construction a glass cylinder entirely surrounds the usual gauze, and fits into a socket at the top. There is a wire gauze disc in the top of the lamp."

Mr. Morison also submitted another lamp to the Committee of the North of England Institute in 1867, which was described as a "modified Stephenson."

The number of modifications of the Mueseler lamp brought out about this time testifies to the high opinion which had been formed of it in Belgium and to some extent in France. M. Habets, in a paper† descriptive of the mining exhibits at the Paris Exhibition (1878), remarked that the safety-lamp showed no striking progress—only here and there the application of some ingenious detail. The increasing favour shown generally to the Mueseler lamp was a lesson to be learned from the exhibits, a favour which was justified by the tests which the lamp had stood—for example, in the accident at Agrappe.

* This lamp was tested by the Committee of the North of England Institute of Mining and Mechanical Engineers, 1867; the St. Étienne Commission, 1867-1868; the Belgian Commission, 1867-1873; and by the British Commission, 1879-1886 (appendix xxiv., fig. 19). It was described by M. G. Arnould in his account of his visit to England, *Annales des Travaux Publics de Belgique*, 1868, vol. xxvi., page 1.

† *Revue Universelle des Mines*, 1880, series 2, vol. viii., page 299.

In France in 1872 the administration issued an "Instruction"* relative to safety in mines, in which attention was directed to the advantages offered by the Mueseler lamp. In 1880 M. Haton de la Goupillière† stated that in France the Mueseler and Dubrulle lamps were considered to be the best, but that the Boty was used also, and, too frequently, the Davy. M. J. B. Marsaut‡ was evidently in favour of the Mueseler lamp, and his well-known investigations were undertaken with the view of improving that lamp. In 1871 he brought out a modified Mueseler without the gauze diaphragm—in fact, a kind of bonneted Boty or Clanny fitted with a chimney.

The Report of the Belgian Commission of 1867-1873 mentioned a British lamp of *Dr. Irvin* which emitted a sound in the presence of firedamp—"La lampe chantante du Docteur Irvin." It was described as a kind of lantern, with glass on one side, and a handle on the other. Air entered the lamp below the wick through a vertical gauze, and then passed through a horizontal gauze to the flame. The products of combustion passed out through the top of the lantern, which was coned upwards, and was covered by a very short gauze cylinder. On the top of the lantern below the gauze cylinder was the apparatus by the vibrations of which the presence of gas was indicated.§

In 1878 or 1879 experiments on safety-lamps were conducted at Brynn by Messrs. William Smethurst and James Ashworth.‖

Firedamp from the Wigan Six or Nine-Foot Seam was used, and a velocity of explosive current up to 38 feet per second was obtained for a period of three minutes. The lamps tested (as classified in the paper) were as follows:—

Davy type: Ordinary Davy; large and small Scottish lamps; improved Davy by Smethurst; improved Davy by Ashworth & Woolrych; Davy of small diameter gauze cylinder by Mr. U. E. Dickinson; and "Jack" lamps.

* "Rapport présenté au Nom de la Commission d'Étude des Moyens propres à Prévenir les Explosions du Grisou," by M. Haton de la Goupillière, Ingénieur en Chef des Mines, Professeur d'Exploitation des Mines à l'École des Mines, *Annales des Mines*, 1880, series 7, vol. xviii., page 358. † *Ibid.*, page 357.

‡ "Étude sur la Lampe de sûreté des Mineurs," by J. B. Marsaut, *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 321.

§ Report of the Belgian Commission, 1867-1873, *Annales des Travaux Publics de Belgique*, 1873, vol. xxxi., page 306. This evidently refers to the lamp of A. K. Irvine patented in 1871 (No. 1896); see also *Transactions of the Mining Institute of Scotland*, 1880-1881, vol. ii., page 162.

‖ *Transactions of the Manchester Geological Society*, 1878-1879, vol. xv., page 113.

Clanny type: Large and small Clanny; Mueseler lamps by various makers, Williamson, Pelton, Bainbridge, Eloin, Gray, and Glover & Cail.

Stephenson type: The ordinary Stephenson, and Williamson.

The conclusions arrived at were as follows:—

The greater the diameter of the gauze, the more quickly flame will pass. In an explosive atmosphere passing at as low a velocity as 7 feet per second and without coal-dust, the ordinary Davy lamp was unsafe. In many cases the Clanny and Bainbridge lamps had proved no safer. Flame would pass through the gauze of the Davy lamp by concussion without the gauze becoming red hot.

A tin shield placed on a Davy lamp was no safeguard against the passage of flame, but the safety of the lamp was increased by the use of a cylindrical glass shield, as in the "Jack" lamp, provided that the glass shield overlapped the top of the smoke gauze by over a quarter of an inch. Smethurst's "Jack" lamp, and Ashworth & Woolrych's "Jack-Davy" lamp were still safer.

The most severe test to which a lamp could be put was exposure to a current containing a very small percentage of gas, just long enough to elongate the flame, and followed by a highly explosive body of gas: very few lamps could stand this. The fact had already been noticed by the Belgian Commission.* Of all the lamps tested—

"the one that gives the steadiest and best light, simple construction, and self-extinguishing, is the Mueseler; and it is also the best for proving the existence of a small percentage of gas in the ventilating current. The Clanny lamp is very little, if any, safer than the Davy lamp. The Eloin is quite safe but too sensitive, the Gray and the Pelton are safe but very heavy."†

In 1878 some experiments on safety-lamps were carried out at the Cannock and Rugeley Collieries, using "ordinary coal-gas."‡

* In the Report of the Belgian Commission of 1867-1873, the following remark occurred:—"La lampe est d'abord éteinte au moyen d'une venue de gaz assez forte, qui est maintenue pendant quelques instants, pour amener l'échauffement des parties métalliques. La venue de gaz est ensuite diminuée graduellement, à peu près jusqu'au point ou le mélange va cesser d'être combustible; il se produit ordinairement, à ce moment, ou l'extinction totale de la lampe, ou le passage de la flamme, par la cheminée, dans le cylindre en toile métallique. Dans ce dernier cas, l'explosion est inévitable, surtout si l'on a soin, au même moment, d'augmenter un peu la proportion de gaz" (*Annales des Travaux Publics de Belgique*, 1873, vol. xxxi., page 309).

† *Loc. cit.*, page 132.

‡ "On the Construction and Comparative Merits of the Safety Lamps Generally in Use," by Mr. Alan C. Bagot, *Transactions of the Institution of Mechanical Engineers*, 1879, page 219.

On June 28th, 1879, a Commission was appointed in Belgium by an "Arrêté Royal" to draw up a programme of investigations to be made on the subject of explosions of firedamp. This programme was issued in 1880, and contained directions as to the testing of safety-lamps.

## XIII.—Period 1880 to 1887.

This period was one of great activity in the investigation of safety-lamps. Government Commissions on firedamp in France, Prussia, and Saxony, and a Royal Commission on accidents in mines in Great Britain were engaged in testing the safety of various forms of lamp, and the principles involved in their construction. Their reports were presented during the period under review, and contributed materially to the growth of knowledge on the subject. Careful investigations were undertaken, not only into the safety of the lamps themselves, but into questions connected with the illuminants used, the methods employed for locking lamps, the best size of gauze and form of gauze cap to be employed, the dimensions of the parts of the lamps, and the use of electric lamps and firedamp indicators.

The French Firedamp Commission of 1878-1882, and the Prussian Firedamp Commission of 1880-1887 in particular, carried out a lengthy series of experiments on the liability of various forms of lamp to internal explosion. In Belgium a permanent committee appears to have been engaged in testing and experimenting on safety-lamps.

In addition to these Government enquiries, useful work was done by individuals and societies connected with coal-mining. The importance of the investigations conducted by M. J. B. Marsaut was generally recognized, while the tests on safety-lamps conducted by the Midland Institute of Mining, Civil, and Mechanical Engineers * were of great value in showing the comparative safety of various kinds of lamp in currents of explosive mixture moving at high velocities. Tests were also carried out by the Mining Institute of Scotland.

One effect of these numerous enquiries was to bring into prominence a large number of safety-lamps, those examined by

* *Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers*, 1883-1884, vol. ix.: first report, page 98; second report, page 266; third report, 1884-1887, vol. x., page 83.

the British Royal Commission (1879-1886) being especially numerous. Many of these lamps had been invented in previous periods, but a considerable number were of recent origin, while some were improvements of older lamps. Doubtless the increased interest shown in the subject acted as a stimulus to invention, while the generosity of Mr. Ellis Lever, who offered a prize of £500 for a miner's safety-lamp which would fulfil certain conditions as to illuminating power, convenience, and safety, acted as a further incentive.

Of the newly invented lamps, the most important appears to have been that invented by M. J. B. Marsaut (Chief Engineer of the Bessèges Coal Company, Gard, France)—a lamp which has had considerable influence on recent developments of the safety-lamp, and is itself extensively used at the present time. Apart from the proportions given to various parts of the lamp, which were determined by M. Marsaut's investigations, the most important innovation in the lamp was the adoption of the bonnet (*cuirasse*).

It has already been mentioned that Sir Humphry Davy was fully aware of the danger which might arise from the use of his lamp in a current of explosive mixture moving at some velocity, owing to the passage of flame through the gauze, and that he recommended the use of a shield, of a double-gauze cap, and of other contrivances to obviate this danger. The Davy shield, however, afforded a very limited amount of security, and was not designed to cope with the higher velocities of air-current which were used in mines in later years. The " Instruction pratique " issued in France in 1824 drew attention to the importance of the use of a shield (*écran*), and suggested several arrangements which might be adopted.

The Upton & Roberts lamp was one in which the Davy gauze was entirely shielded; Dr. Clanny's fifth lamp (1839) was also a shielded lamp, but in it the inlet of air was from over the top of the shield, exactly the opposite to the arrangement in a bonneted lamp.

Mr. Nicholas Wood in 1853 drew attention to the increased safety afforded to the Davy lamp by a complete shield, while the Tin-can Davy—a completely enclosed Davy—was invented in 1865. The use of a shield was also recommended by the St. Étienne Commission (1867), and by Messrs. W. Smethurst and J. Ashworth in 1878.

It seems open to question who it is to whom the invention of the bonnet is due. M. Ed. Harzé* stated that M. Gér. Godin and M. G. Arnould were aware of the efficacy of the bonnet applied to the Mueseler lamp, and that both of them submitted bonneted lamps of this type to the Belgian Commission in 1868. The Commission, however, was not in favour of an arrangement which would completely hide the upper part of the lamp, and thus prevent inspection. M. G. Arnould was certainly impressed with the advantage of a bonnet.

M. Haton de la Goupillière attributed to M. Marsaut the model of the bonnet now generally used.† M. Marsaut used a bonnet in his lamp invented in 1871.

In 1881 M. Birckel invented a lamp with a double casing, which may be regarded as a kind of bonnet.

In the Report of the Midland Institute on the tests on safety-lamps conducted at Aldwarke Main in 1884, mention was made of bonnets shielding or screening the whole of the gauze ("Smethurst's type").

The British Royal Commission on Accidents in Mines in 1886 also mentioned "an external jacket or bonnet, as proposed by Mr. William Smethurst and Mr. Ashworth."

The increase of safety afforded by a bonnet is now generally recognized, and the "permitted" lamps in Great Britain, Belgium, and France are all furnished with this contrivance. Considering the value that was in early days attached to the use of a shield, it seems rather strange that so many years elapsed before the bonnet came into use.

The objections brought against it appear to have been three —the fact that by obscuring the upper part of the lamp it rendered it possible for a lamp to be sent into the pit in a defective condition; the idea that a bonnet, by shielding the gauze from the direct action of the air-current, caused heating in the gauze; and the extra weight entailed by its use.

Despite these objections, the increase of safety brought about by the use of a bonnet was clearly recognized in Great Britain and acknowledged by the Committee of the Midland Institute and by the Royal Commission of 1886. The Royal Commission made a suggestion for overcoming the first objection

* *Annales des Mines de Belgique*, 1906, vol. xi., page 75.

† *Cours d'Exploitation des Mines*, 1911, vol. iii., section 2,449.

mentioned above. The French Commission, in its Report issued in 1882, while favourably impressed with a bonneted lamp* submitted by M. Marsaut, evidently considered the bonnet a drawback, because it concealed the gauze cap.†

The Sub-commission on Safety-lamps of the Prussian Firedamp Commission seems to have been favourably impressed with the value of a bonnet in preventing the passage of flame through the gauze in explosive currents of high velocity, and quoted the experiments at Aldwarke, but made no definite recommendations as to its use.

The Royal Commission on Accidents in Mines (1886) in Great Britain was followed by the passing of the Coal Mines' Regulation Act of 1887. This Act contained provisions respecting the compulsory use of safety-lamps in certain circumstances, the construction of safety-lamps, and with regard to other matters affecting the employment of safety-lamps.

In Belgium an "Arrêté Royal" in 1884 appears to have relaxed the stringency of previous legislation respecting the exclusive use of the Mueseler safety-lamp in mines containing firedamp. By this decree such mines were divided into three categories, and the use of the Mueseler lamp was made compulsory in mines of the second and third categories, that is, mines which contained firedamp (as distinct from those which contained little firedamp), or were liable to sudden outbursts of firedamp. Even in such mines, other specified forms of safety-lamp were permitted to be used for certain purposes.

It is interesting to note that, while the Prussian Firedamp Commission recommended that in safety-lamps constructed with a glass cylinder air should be supplied from above the flame, the Saxon Firedamp Commission considered that such lamps were more dangerous than those in which air was supplied from below the flame.

In order to overcome an objection made to the bonnet—that it prevented the omission of any important part of the

* It would seem that this was the earlier lamp, invented by Marsaut in 1871, and not the well-known Marsaut lamp (see "Étude sur la Lampe de Sûreté des Mineurs," by J. B. Marsaut, *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 324).

† "On ne peut dès à présent lui addresser qu'un seul reproche, c'est que la toile métallique est cachée par un écran, ce qui empêche de constater d'un simple coup d'oeil la présence ou l'absence de cet élement essentiel de la sécurité."

upper portion of the lamp from being easily detected—various forms of removable bonnet were introduced, arrangements being made to prevent the bonnet from being tampered with, either by locking it with a lead rivet, by a pin working on the oil-vessel, or on the locking arrangement, or by other similar devices.

The introduction of the bonnet facilitated the application of a "shut-off" to the safety-lamp—that is, an arrangement which, by cutting off the access of air, would extinguish any flame burning in the lamp. This idea was by no means new, as an arrangement for this purpose was used in Dr. Clanny's lamp (fourth type) before 1835, and in this case the extinguishing arrangement was designed to come into operation automatically when a wire of fusible metal was burned through by the increased heat in the lamp. In bonneted lamps the "shut-off" was effected by an arrangement which enabled either a ring* or the bonnet to be turned slightly so as to close the inlet-holes, or the inlet and outlet-holes; in some cases the arrangement was automatic, depending on the action of a spring which came into operation when a string was burned through, or a plug or a wire fused.

The screw-lock, either in its original or in improved forms, and the riveted lead plug appear to have been the most generally used methods for locking lamps.

The British Royal Commission on Accidents in Mines (1886) particularly mentioned the lead plug as being "the simplest and most effective means of preventing lamps from being surreptitiously opened." Various locks, operated either by an air-pump or by a powerful magnet, had been introduced; and the Wolf magnetic lock appears to have favourably impressed both the British and the Prussian Commissions as being simple and satisfactory. The latter Commission mentioned also the magnetic lock of Schondorff.

Improvements had also been effected in illuminants. In addition to the use of pure vegetable (rape or colza) oil and seal oil, a mixture of either of these oils, with a proportion of mineral oil (petroleum), appears in some cases to have been adopted—a practice which received favourable comment from

* Such an arrangement was attached by M. Marsaut to the bonneted lamp introduced by him in 1871.

the British Royal Commission. Light refined mineral oils were also being introduced—colzaline in the Protector Company's lamps and benzine in the lamps made by the firm of Friemann & Wolf.

The use of electric light received considerable attention from the British Commission. Attempts were made at Pleasley Colliery and at Earnock Colliery in 1881 to apply this light in the form of fixed incandescent lights for the illumination of the workings, but without success. A number of forms of portable electric lamps were examined by the Commission, which reported that considerable progress had been made in this direction, and expressed the opinion that before long improvements would be made which would enable such lamps to be used generally at collieries.

During this period a number of firedamp indicators were devised, but as only one of them—that invented by Herr Pieler, an Austrian engineer—depended on the flame-test, they do not come within the scope of this paper.

The French Commission on Firedamp owed its origin to a law of March 26th, 1877, proposed by M. Paul Bert, but the members do not appear to have been nominated until January 8th, 1878. The Report of the Commission was presented on March 20th, 1882, by the President, M. A. Daubrée. A special Report presented by MM. Mallard and Le Chatelier on the tests with safety-lamps, which were carried out by a Sub-commission, was published as an appendix.* The results of these tests were stated to be in accordance with those already obtained by Commissions of English engineers, by the Commission of St. Étienne, and by the Belgian Commission of 1867-1873.

Lamps protected by a simple gauze passed flame easily in a current of explosive mixture of air and lighting-gas at a velocity of 2 metres (6½ feet) per second. Lamps of most other systems also allowed flame to pass under the ordinary conditions of employment, and they only differed one from the other in the greater or less velocity necessary to produce this result.

The Sub-commission had only been able to pass flame through the Belgian Mueseler "type" lamp with some difficulty,

* Several detailed accounts of researches undertaken in connexion with the Commission were given in the *Annales des Mines* (Paris).

but they had done so in a current directed downwards from above the lamp ("en projetant sur la lampe un très fort courant dirigé presque suivant la hauteur de la lampe et de haut en bas"). Hence they concluded that the lamp was not a certain safeguard against explosions, but that it was much safer than any of the others ("mais elle présente une securité incomparablement plus grande que toutes les autres"), descending currents being the only condition to fear with this lamp. They, therefore, strongly recommended the adoption of the Mueseler lamp.

Favourable mention was made of a lamp recently submitted by M. Marsaut, which was extinguished in gas, and had not passed flame even in the strongest currents, moving in any direction. The only objection to the lamp was the shield, which hid the metal gauze.

On February 12th, 1887, a new French Firedamp Commission was instituted, which was subsequently made permanent by a decree of February 4th, 1891.

An experimental lamp designed by MM. Mallard and Le Chatelier* was a Mueseler taking in its air both above and below the flame. The bottom of the chimney was placed rather further above the flame than in the Belgian "type Mueseler," and the top of it was flattened ("le sommet de cette cheminée est très aplati"), so as to present an obstacle to the passage of flame.

As a result of the experiments made by Marsaut, Le Chatelier suggested that for the diaphragm of the Mueseler lamp the gauze of 144 apertures per square centimetre (934 apertures per square inch) should be replaced by a gauze of 196 apertures per square centimetre (1,272 apertures per square inch).†

About the year 1882 M. J. B. Marsaut was making some investigations on a modified Mueseler lamp (bonneted, without a diaphragm, but with two chimneys) which he had invented, with the view of getting rid of some of the disadvantages of the

* "Rapport présenté au Nom de la Commission d'Étude des Moyens Propres à prévenir les Explosions du Grisou," by M. Haton de la Goupillière, Ingénieur en Chef des Mines, Professeur d'Exploitation des Mines à l'École des Mines, *Annales des Mines*, 1880, series 7, vol. xviii., page 193.

† "Rapport sur les Lampes de Sûreté," by H. Le Chatelier, *Bulletin de la Société de l'Industrie Minérale*, 1889, series 3, vol. iii., page 575.

Mueseler lamp, especially its liability to extinction when tilted.*

These investigations were made in a glass bell, into which illuminating-gas could be admitted. Marsaut found that, on raising his lamp into the glass bell to receive the gas, lowering it again, and stopping it opposite to the edge of the bell (in order to cause an internal explosion at the height at which the gas was mixed with air in suitable proportion), ignition of the gas in the bell took place at nearly every trial.†

This discovery led M. Marsaut to test other lamps, several of which were found to exhibit the same phenomenon. The Belgian Mueseler in 3,570 tests gave 20·9 per cent. of passages of flame across the diaphragm, and 1·3 per cent. of outside explosions. On the other hand, the Marsaut, English Mueseler, Fireman's Davy, Boty, and Westphalian lamp with protected inlet ring, gave no outside explosion. The Mueseler-Arnould-Godin and the Evan Thomas (double-glass type) lamps from their construction did not give rise to internal explosion.

M. Marsaut then proceeded to examine the bearing of the construction of safety-lamps on their liability to internal explosion, and obtained a number of most important results, which are set forth in full in his paper. From a consideration of these and from experiment, Marsaut was led to the invention of the lamp which bears his name. He found that firedamp was less inflammable than lighting-gas.‡ He considered that the most dangerous conditions that could arise were:—

(1) When a rapid current of explosive mixture flowed suddenly on to the lamp. This gave two chances of external explosion—(*a*) due to the mechanical action of the current, and (*b*) due to internal explosion.

(2) Those which created the mixture most quickly, and for this an atmosphere surcharged with gas appeared to be necessary. A lamp suddenly introduced into gas might become

* "Étude sur la Lampe de Sûreté des Mineurs," by M. J. B. Marsaut, *ibid.*, 1883, series 2, vol. xii., page 321. A translation of this paper by Mr. T. Carrington appeared in the *Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers*, 1883-1884, vol. ix., page 111; and by Messrs. J. A. Verner and W. H. Routledge in the *Transactions of the Chesterfield and Derbyshire Institute of Mining, Civil, and Mechanical Engineers*, 1884, vol. xii., page 179.

† This phenomenon of internal explosion in a still atmosphere was called by M. Haton de la Goupillière "l'effet Marsaut," and by the Prussian Firedamp Commission "Durchschlag."

‡ *Op. cit.*, page 359; see also page 370.

charged with explosive mixture on account of the air which it contained, similarly in the case of a lamp full of gas brought into air.

He noticed the apparent paradox—"The lamps resisted better in the most inflammable mixtures than in others which, from their composition, appeared less dangerous."*

M. Marsaut also conducted experiments on the resistance of metallic gauzes of safety-lamps to the passage of flame, and made photometric tests.

M. Marsaut's experiments were repeated by MM. Mallard and Le Chatelier using the lighting-gas of Paris.† With the Belgian Mueseler lamp in 50 to 60 tests no passage of flame outside the gauze occurred, although several times flame passed into the gauze cylinder. MM. Mallard and Le Chatelier then tried an electric spark instead of flame; with the spark 5 to 6 millimetres (0·2 inch) above the ring of the wick-tube, flame was projected into the gauze cylinder, but not through it; with the spark at the height of the ring of the wick-tube, projection of the flame out of the lamp took place once in about every three tests. The passage of flame took place through the chimney, not through the gauze diaphragm. When using mixtures of air and methane, in every experiment flame passed into the gauze cylinder; but no passage of flame took place out of the lamp, unless the gauze diaphragm was completely blocked.

MM. Mallard and Le Chatelier concluded that the "effet Marsaut" was not likely to be produced with the Mueseler lamp under practical conditions, only with illuminating-gas, not with firedamp as ordinarily occurring. They recommended the addition of a shield (*écran*) to the Mueseler lamp.

M. Marsaut then tried the electric spark, using the lighting-gas of Bessèges. The results were even more striking than those previously obtained, since only the Marsaut lamp with three gauzes and the small Davy resisted the passage of flame in every experiment. He attributed this failure on the part of the lamps to resist the passage of flame to the absence of the products of combustion and of the neutral stratum at the

* *Ibid.*, page 375.

† "Sur les Lampes de Sûreté, à propos de Récentes Expériences de M. Marsaut," by MM. E. Mallard et Le Chatelier, Ingénieurs des Mines, *Annales des Mines*, 1883, series 8, vol. iii., page 35.

bottom of the lamp: the higher the electric spark was placed in a lamp, the greater was the difficulty of producing explosion.

The Prussian Sub-commission on Safety-lamps* remarked that it was curious that the Westphalian lamp with air-inlet ring ("mit Siebring"), which passed flame in almost every case in the experiments at Dortmund and at Bochum, showed only 0·47 per cent. of external explosions (out of 640 tests) in M. Marsaut's experiments.

The British Royal Commission on Accidents in Mines (1886) reported that they had repeated a few of M. Marsaut's experiments, and the results were in general accord with those obtained by him.

MM. V. Watteyne and S. Stassart† repeated the experiments of M. Marsaut, both in lighting-gas and in firedamp. With the Mueseler lamp using lighting-gas they obtained a few passages of flame into the gauze cap, but with firedamp this effect was not produced, although more than 300 tests were made. They agreed with the French Commission that the difference must be due to the different composition of the gas in which the tests were made.

The *Marsaut lamp* (Figs. 34 and 35), which was the result of M. Marsaut's experiments, was an improvement of an earlier lamp introduced by him in 1871, which was a kind of bonneted Boty or Clanny with a chimney, derived from the Mueseler by suppression of the diaphragm.‡

In this lamp a thick glass was employed, in order to diminish the internal diameter, and to avoid any rapid contraction of section between the glass and the gauze. A flat wick was used, of as large a size as practicable, and the wick-tube was raised in the glass, in order to increase the volume of the compressible stratum at the bottom.

The flat diaphragm and chimney of the Mueseler lamp were replaced by an interior gauze cap, offering a larger surface for the escape and for the cooling of the heated gases. Over this

* *Anlagen zum Haupt-Berichte der Preussischen Schlagwetter-Commission*, vol. iii., page 71.

† "Expériences sur les Lampes de Sûreté," by V. Watteyne and S. Stassart, *Annales des Mines de Belgique*, 1904, vol. ix., page 947.

‡ A later development of this lamp had two chimneys. "Étude sur la Lampe de Sûreté des Mineurs," by M. J. B. Marsaut, *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 328, and fig. 4, plate viii.

interior gauze cap was fixed an exterior cap of gauze; both of them were slightly conical, but the coning of the interior gauze cap was more rapid than that of the exterior one. These

FIG. 34.—PARTS OF MARSAUT LAMP.

FIG. 35.—MARSAUT LAMP.

Figs. 34 and 35 are reproduced by permission of the Authorities from a lamp in the collection at the Science Museum, South Kensington.

gauze caps were surrounded by a bonnet, at the bottom of which, just above the glass, were the holes through which the fresh air entered. The products of combustion left the lamp through

holes punched in the bonnet close to its top, and a short distance above the top of the outer gauze cap. For additional safety* (" pour les plus craintifs," to quote M. Marsaut's own words), a third gauze could be added.

The Marsaut lamp was designed to avoid the inconveniences and sources of danger which the inventor found in testing with the Mueseler. It was not extinguished so quickly when inclined, or in an ascending current of air, or by a rapid descent through the air; it was safe in rapid currents of explosive mixture, even when these were directed obliquely on to the lamp; and it did not produce internal explosion when re-introduced into a stagnant explosive mixture of illuminating-gas and air (" l'effet Marsaut ").

Tests on the Marsaut lamp appear to have been carried out by a Commission of the District du Sud-Est de la Société de l'Industrie Minérale.†

Nine examples of this lamp were submitted to the British Royal Commission on Accidents in Mines of 1879-1886, and the Marsaut lamp was one of the four which received special mention in the Report of that Commission. The Austrian Firedamp Commission of 1890 also found the lamp quite satisfactory. It passed the tests applied by MM. Watteyne and Stassart at Frameries (Belgium) in 1904, and was one of the lamps authorized for use by the Belgian Decree of August 19th, 1904. Many of the lamps " permitted " for use in Great Britain under the Coal Mines Act of 1911 belong to this type.

The Saxon Firedamp Commission was appointed on January 11th, 1880, in consequence of an accident on December 1st, 1879, at Brückenbergschacht II. at Zwickau. The enquiry into the subject of safety-lamps was conducted by Bergrath G. Kreischer and Bergrath Dr. Cl. Winkler. These gentlemen presented their report to the Commission in 1884.‡

* *Op. cit.*, page 458.

† These are mentioned in the Report of the Safety-lamp Sub-commission of the Prussian Firedamp Commission, page 80, but the writers have been unable to trace the reference.

‡ " Untersuchungen über Sicherheitslampen. Bericht an der Königlich Sächsische Commission zur Revision der bergpolizeilichen Sicherheitsvorschriften," erstattet von Bergrath G. Kreischer, Professor der Baukunde, und Bergrath Dr. Cl. Winkler, Professor der Chemie, an der Königlichen Bergakademie zu Freiberg, *Jahrbuch für das Berg und Hüttenwesen im Königreiche Sachsen*, 1884, page 1.

Investigations were undertaken as to illuminants, methods of locking, gauzes, wicks, and the illuminating power of various lamps.

The tests on lamps were carried out in a glass cylinder, into which the explosive mixture was introduced through a pipe: the apparatus was described, with an illustration, in the Report. Both mine-gas and illuminating-gas were used. The lamps tested were of types already in use in Saxony, giving good light, and being good firedamp indicators, namely, Wolf benzine lamp, with under air-feed; Wolf benzine lamp, with over air-feed; Rabe and Wolf lamp, burning rape oil, with under air-feed; lamp with over air-feed, burning rape oil and fitted with the magnetic lock of Schondorff (Patent Koetz); Winkler's lamp, with under air-feed, burning rape oil and petroleum.

The Mueseler lamp was not tested, as it was not considered a good indicator of firedamp on account of the chimney. Lamps of complicated construction were not tested. The Davy and Stephenson lamps were tested in the earlier experiments, but were rejected on account of the poor light they gave, and because as indicators they were inferior to the other lamps.

The tests were made with normal and reduced flames and in percentages of gas varying from 1 to 16.

The Report stated that lamps in which continued burning of gas in the lamp ("die bleibende Aureole") occurred were more dangerous than those in which such burning gas was soon extinguished, or in which the gas did not burn. For this reason, contrary to the usual opinion, it would seem that lamps with over air-feed were more dangerous than those with under air-feed.

All the lamps tested were said to indicate as low as 1 per cent. of gas, but not less, but the Pieler indicated down to ¼ per cent. of gas.

In 1884 the Midland Institute of Mining, Civil, and Mechanical Engineers appointed a Committee to test safety-lamps and to report on them.* The tests were carried out in an apparatus of the trough type at the Aldwarke Main Col-

* *Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers*, 1883-1884, vol. ix.; first report, page 98; second report, page 266; third report, 1884-1887, vol. x., page 83.

liery of Messrs. John Brown & Company, Limited, under the superintendence of Mr. C. E. Rhodes. The first Report stated that—

"in an explosive current ranging from 6 to 14 feet per second in velocity, the Davy, Clanny, Stephenson, Williamson, Thompson, Bainbridge, and ordinary Mueseler of the Belgian type were all absolutely unsafe, and further trials were therefore deemed unnecessary."*

The Protector Mueseler, Saint's Improved Mueseler, the Purdy lamp, the Routledge & Johnson, lamps fitted with bonnets shielding the whole of the gauze ("Smethurst type"), and the Marsaut, were further tested, some of them up to 35 feet per second, and in currents directed obliquely on to the lamp.

The second Report stated that the apparatus had been altered to give velocities up to 51 feet per second, but that at the highest speed the duration of the test could not be sufficiently long to enable the observers to see what would ultimately happen. The only lamps that stood the trials without firing the explosive mixture outside were Mueseler lamps fitted with a bonnet or shield ("Smethurst type"), the Thomson lamp No. 2, and Saint's Mueseler No. 3, "which are also fitted with a bonnet or shield and have each a chimney inside the gauze, and are therefore of the Mueseler class."†

The Committee found that no lamps had stood the tests so well as those of the Mueseler type, fitted with a bonnet; although the gas continued to burn in these lamps all through the experiments at the highest velocities, in no case had flame been communicated to the explosive mixture outside.

An almost continuous series of tests on safety-lamps appears to have been carried on in Belgium during this period. From 1882 to 1885 such tests were conducted by the engineers of the Belgian Administration of Mines at the collieries of Messrs. John Cockerill & Company, Seraing, near Liége, and in 1888 and 1889 at the gas-works at Liége. In 1892 an installation was erected at the Tilleur Pit of the Horloz Collieries.‡

On April 28th, 1884, an "Arrêté Royal" relating to mines was published by the Belgian Government.§ By Section II., Art. 24, mines containing firedamp ("mines à grisou") were divided into three categories, namely:—

* *Ibid.*, vol. ix., page 98. † *Ibid.*, page 267.

‡ See papers by MM. Watteyne and Stassart, *Annales des Mines de Belgique*, 1902, vol. vii., page 993; also annexe i., page 1085: 1904, vol. ix., page 961.

§ *Annales des Travaux Publics de Belgique*, 1885, vol. xlii., page 111.

(1) Mines containing little firedamp ("peu grisouteuses"),
(2) Mines containing firedamp ("grisouteuses"), and
(3) Mines liable to sudden outbursts of firedamp.

Section III., Art. 43, laid down that the use of safety-lamps burning pure vegetable oil was obligatory for mines containing firedamp. Art. 44 required that the Mueseler "type" lamp, made in accordance with the official regulations, should be the only kind of lamp used in mines of the second and third categories, although slight variations of size and of shape were permitted. Dimensions and drawings of the "type" lamp and of the limits of variation were annexed. The use of the Mueseler Porion* (without horizontal gauze or chimney, but with two gauze caps), of the Mueseler Godin, and of the Davy was permitted to certain officials and for certain purposes. The "chargeages" were allowed to be lighted by a large form of Mueseler ("Mueseler de grand format").

In 1884 and 1885 Mr. A. R. Sawyer, Assistant Inspector of Mines, carried out some interesting tests on safety-lamps of various types and on the Mueseler in particular.†

In 1879 a Royal Commission on Accidents in Mines was appointed in Great Britain, which reported on March 15th, 1886. A most exhaustive examination of over 250 safety-lamps was made. Experiments were carried out with natural firedamp at Garswood Hall Colliery, Lancashire, and at Llwynypia Colliery, South Wales; and with lighting-gas at Woolwich Arsenal. The results were given in Appendix XXIV. of the Report, which contained a short description of each lamp tested, and an illustration of some of the lamps. The conclusions arrived at by the Commission cannot, for lack of space, even be summarized in this paper, and it would be unnecessary to do so in the case of a Report so easily accessible and of so recent a date. Out of all the lamps examined by the Commission, four—the Marsaut, bonneted Mueseler, the Gray, and the Evan Thomas No. 7—were selected for special mention as combining "the quality of safety, in a pre-eminent degree," with "simplicity of construction and with illuminating power at least fully equal to that of

* "La Lampe Mueseler, dite de porion."

† *Transactions of the North Staffordshire Institute of Mining and Mechanical Engineers*, 1884-1885, vol. vii., pages 160, 200, and 307.

any of the lamps hitherto in general use." A warning was given that, with all Mueseler lamps, care must be taken to avoid a considerable inclination from the vertical. Other lamps which were favourably mentioned were those of Hann, Morgan, Purdy, and Soar. It was pointed out "that in the present improved ventilation of collieries, ordinary Davy and Clanny lamps have ceased to afford protection from explosion, and that the Stephenson lamp, though more secure than the two former, cannot be relied on."

The Commission considered that it would be unwise to make any particular lamp compulsory, "as calculated to throw difficulties in the way of introducing improvements which will no doubt arise in the future": they thought, however, that some control should be exercised in reference to types of lamps employed, and that "only those lamps should be used which are authorized from time to time by the Secretary of State." Recommendations were made relative to the testing of lamps before they were used underground, as to the locking of lamps, and respecting illuminants. The Commission devoted considerable attention to the use of electric light in coal-mines.

The Prussian Firedamp Commission, appointed on October 18th, 1880, issued its Final Report in July, 1887.* The subject of safety-lamps was delegated to a Sub-commission,† the testing of the lamps being carried out in the laboratory at Bochum under the supervision of Dr. Schondorff. Lighting-gas was used in some tests, and natural firedamp from blowers at the Bonifacius Mine in others. The apparatus used was of the box type, and was made to serve both for tests on lamps in a still atmosphere and, with certain alterations, on lamps in moving currents of explosive mixture: great attention was paid to the behaviour of lamps under both these conditions. The experiments of M. Marsaut were repeated, not only with the ordinary and reduced flames, but also with the electric spark at various heights; the limits of explosibility were also studied both with respect to internal explosion ("Durchschlags-Intervallen") and to "blowing through" ("Durchblase-Inter-

* *Haupt-Bericht der Preussischen Schlagwetter-Commission*, 1887; translated by Dr. P. Phillips Bedson and L. L. Belinfante, *Trans. Inst. M. E.*, vol. iii., page 1105; vol. iv., page 631; and vol. v., page 500.

† "Schluss Bericht der Lampen-unter-Commission," *Anlagen zum Haupt-Berichte der Preussischen Schlagwetter-Commission*, 1886, vol. iii.

vallen "). Investigations were carried out respecting the influence of more than one gauze cap, of a chimney, of dirt on the gauzes, and of defective gauzes, on the safety of the lamp.

With respect to internal explosion, the Commission found—

(1) That lamps without glass were less liable to this than lamps fitted with a glass cylinder, and that the safety of lamps increased in direct ratio of the surface of the wire gauze and in inverse ratio of the cubical content of the lamp.

(2) For the same surface of wire gauze the conical shape was safer than the cylindrical; sudden contractions favoured internal explosion.

(3) For the same thickness of gauze the safety of a lamp increased with the closeness of the mesh; or, the closeness of the mesh remaining constant, safety increased with the thickness of the gauze.

(4) Admission of air from below, and the use of a chimney such as that of the Mueseler lamp, increased the liability of a lamp to internal explosion.

(5) The use of superimposed gauzes (as in the Marsaut) reduced the risk of internal explosion.

With respect to the liability of lamps to have the flame blown through the gauze—

(1) The danger, as in the case of internal explosion also, was greater in illuminating-gas than in pit-gas.

(2) The risk varied directly as the velocity of the air-current passing; as the sectional area of the current; and as the amount of gas present in the current, in this case the maximum effect being attained before the percentage of gas present was sufficient to form the most explosive mixture.*

(3) Liability to " blowing through " decreased as the thickness or closeness of the wire-gauze increased. Double-wire gauzes were safer than single gauzes, but only to a certain extent.

Since the wire-gauze must be incandescent before the passage of flame could take place, a warning was given.

The safety-lamp was reported to be the best means of testing

* The Sub-commission on Safety-lamps laid stress on this in their remarks on page 161—" Ausserdem ergeben die Versuche der Tabelle L auch wieder die eigenthümliche Thatsache, dass für die geringeren Geschwindigkeiten die oberen Grenzen des Durchblase-Intervalles unterhalb des Procentsatzes von maximaler Explosibilität liegen. Es folgt hieraus der wichtige Satz:— Wenigstens für die geringeren Geschwindigkeiten des Gasstromes besitzt nicht etwa das explosibelste, sondern ein geringwerthigeres Gemisch die durchblasefähigste Wirkung."

for firedamp, and the Davy gave the clearest indications; but the Saarbrücken Boty and the Wolf benzine lamp were nearly as good. The Mueseler was considered least suitable as an indicator, especially those varieties in which the chimney came near to the flame, as the indications began later, and the most important appearances of the flame were concealed by the chimney. A somewhat similar objection applied to bonneted lamps.

The Commission laid down certain principles as to the construction of safety-lamps, and the sizes and proportions of their parts. The conclusion arrived at was that "of all the various forms of lamp in current use, no single one can be pointed to as fulfilling all the above requirements." Some did not comply with the fundamental principles of the Davy lamp; some were too liable to internal explosion or to "blowing through," or were of too low a standard of illuminating power; others were too complex in construction. It was not considered wise to prescribe the use of any particular lamp of invariable construction.

In 1886 the Mining Institute of Scotland appointed a Safety-lamp Committee, which carried out tests and issued a report. Lamps of the Marsaut type and the Protector Mueseler were recommended.*

Tests on safety-lamps were also conducted in 1887 by Mr. W. Clifford in an apparatus erected at the Neepsend Works of the Sheffield Gas Company.†

In Great Britain the Coal Mines Regulation Act of 1887 contained provisions requiring the use of locked safety-lamps in any place in which there was likely to be any such quantity of inflammable gas as to render the use of naked lights dangerous, or in any working approaching near a place in which there was likely to be an accumulation of inflammable gas; also provisions as to the use of mixed lights, the construction and examination of safety-lamps, the position of underground lamp-stations, and certain other matters connected with safety-lamps. As to the construction of safety-lamps, the Act required that—

"Wherever safety-lamps are used, they shall be so constructed that they

* *Transactions of the Mining Institute of Scotland*, 1887-1888, vol. ix., page 44.

† *Transactions of the Chesterfield and Midland Counties Institution of Engineers*, 1887-1888, vol. xvi., pages 128, 149, and 165.

may be safely carried against the air-current ordinarily prevailing in that part of the mine in which the lamps are for the time being in use, even though such current should be inflammable."

It would be impossible within the limits of this paper to give even a short description of the various types of lamp tested by the Commissions and Committees which were at work during this period. Further it seems unnecessary to do so, since most of them are fully described in Appendix XXIV. of the *Report of the British Royal Commission on Accidents in Mines*, 1886, in monographs on the safety-lamp, and in books on mining; while the construction of several of the older lamps has already been explained. The writers have, therefore, described in detail only those lamps which were particularly praised or favourably mentioned by the British Royal Commission of 1886, and some other lamps, a description of which is not easily accessible. A list, however, of the lamps reported on by the British Commission of 1886, is given in Appendix I., arranged as far as possible under the types to which they were referred by the Commission.

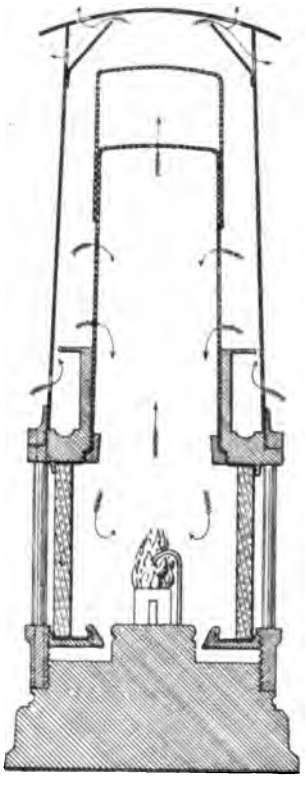

FIG. 36.—EVAN THOMAS LAMP (No. 7).

Reproduced by permission of the Controller of H.M. Stationery Office from the Final Report of the Royal Commission on Accidents in Mines, 1886, appendix xxiv., fig. 33.

Of the lamps which were particularly praised, the Gray and the Marsaut have already been described, while the Mueseler was simply the bonneted form of that lamp; there remains, therefore, only the Evan Thomas No. 7.

*The Evan Thomas No. 7* (Fig. 36) was a bonneted Clanny, having a brass tube an inch high around the lower end of the gauze cylinder; from the top of this brass tube a horizontal brass

flange extended nearly to the bonnet, leaving an annular space of $\frac{1}{16}$ inch, through which the feed-air entered. The outlet-holes were slightly restricted. Of this lamp* the Commission reported—

"The flame is bright and remarkably steady in the strongest air-current we can produce. In an explosive atmosphere moving with a velocity of 3,200 feet per minute [53 feet per second], it showed no signs of danger after an exposure of nearly eight minutes."

Of the lamps which were specially mentioned by the Commission, the Purdy, which was invented in 1879, has been already described; the others were the lamps of Hann, Morgan, and Soar.

Two types of *Hann lamp*† were tested. One type resembled generally the Stephenson, with a gauze cylinder outside a glass cylinder. The glass cylinder was shorter than the gauze cylinder, and on the top of it was a metal tube, which fitted tightly inside the gauze cylinder; this tube was closed at the top by the gauze cap of the gauze cylinder. Air entered the lamp below the flame through perforations in a metal ring guarded by a strip of the lower portion of the gauze cylinder. One of these lamps (No. 5) produced explosion with a current velocity of 3,100 feet per minute (52 feet per second), another (No. 6) with a velocity of 2,857 feet per minute (47 feet per second). The Commission reported that "these lamps certainly seem more secure than the ordinary Stephenson lamps."

*The other Hann lamps* belonged to the Eloin type, having a glass cylinder with a superposed brass tube closed by a disc of perforated sheet-metal. Air was admitted below the glass through large holes protected by gauze. In the experiments one of these lamps failed to produce an explosion in a current passing at 1,926 feet per minute (32 feet per second), but fired the external mixture of gas and air passing at a velocity of 2,857 feet per minute (47 feet per second), the glass being badly cracked by the flame.

*The Morgan**‡ had, inside the bonnet, a metal shield, of the same diameter as the outer diameter of the glass, which encircled the gauze cap and extended some distance above it. The chimney was cylindrical, and was held in its place by a gauze diaphragm

* An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

† *Final Report of the Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 9.

‡ *Ibid.*, fig. 32.

or cap of conical shape joined to the chimney not far from its top; over the top of the chimney was placed a truncated cone of gauze, with the smaller end downwards, closed at the top by a disc of gauze. The exit of air from the bonnet was through a series of annular spaces. The air entering the lamp had to pass through a special inlet arrangement at the bottom of the bonnet, through openings in the inner shield, and over a vertical flange between the inner shield and the gauze cap; it then passed through the lower portion of the gauze cap and through the gauze cap or diaphragm to the flame. The exit of the products of combustion was through the gauze cap of the chimney, the top of the gauze cylinder, and the annular spaces in the top of the bonnet.

This lamp was praised by the British Commission of 1886. It was found to be safe in a current with a velocity of 2,857 feet per minute (47 feet per second); in a still atmosphere it gave a good light; but in a strong current its light was "considerably reduced." The Commission considered that its weight and complicated construction were reasons which might militate against its coming into general use.

The Morgan lamp was tested also by the Austrian Firedamp Commission of 1891.

*The Soar** was a double-glass lamp of the Eloin type, the space between the glasses being closed. On the top of the inner glass cylinder was placed a metal cylinder or tube, in the upper part of the interior of which was placed a short conical gauze cap; the top of the tube was closed by another gauze cap which fitted over it externally. The tube and its two gauze caps were completely closed by a slightly conical bonnet, in the lower part of which air-inlet holes were cut, while the products of combustion escaped through holes in the dome at the top of the bonnet. Air for the flame, however, entered only below the glasses through vertical holes in a ring round the oil-vessel, which was guarded by a vertical strip of gauze. The Commission considered that the lamp afforded a high degree of safety, and gave a fairly good light in still air, but that it was difficult to light, and was extinguished at once by a very slight downward current.

Other lamps which were brought out about this period, and are mentioned in contemporary mining literature, were the following:—

* *Ibid.*, fig. 26.

### *Davy Type.*

*The Pieler lamp** was brought out in 1884 by Herr Pieler, an Austrian engineer, for the purpose of indicating very small quantities of firedamp, down to ¼ per cent. It was a large Davy, with a slightly conical gauze cap, and was constructed to burn alcohol with a circular wick, the alcohol being absorbed in cotton-wool. The flame was surrounded by a short chimney of metal in the shape of a truncated cone. The lamp was protected by a removable bonnet or case, which covered the whole of the gauze cap and rested on a flange projecting from the side of the alcohol reservoir; holes were cut in this flange, to allow of the admission of air to the flame. A long vertical strip of the bonnet was cut away to admit of the insertion of a glass window, through which the flame-cap inside the gauze could be seen. In order to make the lamp more secure, a double-gauze cap was used at the collieries of Lens, France.

*The Routledge & Johnson lamp*† was a Davy lamp placed inside an unbonneted Clanny lamp. In the tests conducted by the British Royal Commission of 1886, the No. 4 lamp of this type was exposed for 90 seconds in a current passing at a velocity of 3,000 feet per minute (50 feet per second), and did not appear likely to ignite the gas outside the lamp.

An American pattern of Davy in Case, in the collection of safety-lamps in the Science Museum at South Kensington, was the *lamp of J. L. Williams and J. Holland* (1885). Air for combustion passed in over the glass shield, and through the gauze, over which arrangements were made for sliding a tube in case of emergency. The gauze was doubled at the top, and outside was a telescopic metal case arranged so as to regulate the supply of air or to cut it off altogether.

### *Clanny Type.*

The following lamps might be classed either under this head or as Botys with over air-feed:—

The *Wolf lamp* had a cylinder of gauze, containing 1,296 apertures to the square inch. Benzine was used as the illumi-

* *Transactions of the North of England Institute of Mining and Mechanical Engineers*, 1884-1885, vol. xxxiv., page 285; 1888-1889, vol. xxxviii., page 177; *Annales des Mines*, 1892, series 9, vol. i., page 51.

† *Final Report of the Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 8.

nant, and the lamp was fitted with an internal igniter and a magnetic lock.

*The Wolf-Westphalian*†* *lamp* (1883-1885) was fitted with a relighter.

*The Wolf-Benzine No. 2*‡ was constructed to burn benzine.

The *Schondoff*‡ had a magnetic lock.

American forms of this type were:—

*The lamp of B. Tappan*,§ in which the glass was replaced by a cylinder of mica.

*The "Mauchline Headlight"*‖ or *Bull's-eye safety-lamp*, which was fitted with a reflector behind the flame, and a lens in front. The Sub-commission on Safety-lamps of the Prussian Firedamp Commission reported that the light given by this lamp was equivalent to 2·8 standard candles.

### *Boty Type.*

*The Birckel lamp* had a double bonnet, one fixed, while the other could be moved horizontally. Both bonnets were pierced with corresponding openings. By turning the movable bonnet, the inlet of air could be regulated. This lamp gained a Monthyon prize of the value of £60 from the Paris Academy of Science in 1881.¶

*The lamp of Dr. Winkler* appears to have been similar to the Bainbridge, but the inlet-holes were guarded with gauze, and a cone was used to direct the entering air on to the flame; a double-gauze cap was used, and a flat wick.

*The Wolf No. 1 Benzine lamp*,‡ and the *lamp No. 3 of Rabe & Wolf*,‡ burning oil, which were tested by the Saxon Commission, were of the Boty type.

* An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington.

† *Die Entwickelung des Niederrheinisch-Westfälischen Steinkohlen Bergbaues in der zweiten Hälfte des 19ten Jahrhunderts*, vol. vii., page 228.

‡ Report of the Saxon Firedamp Commission, *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen*, 1884.

§ *Historia, Descripcion, y Crítica de los Sistemas empleados en el Alumbrado de las Excavaciones Subterráneas*, by A. Gil y Maestre & D. de Cortazar, Madrid, 1880.

‖ Report of the Sub-commission on Safety-lamps, *Prussian Firedamp Commission*, vol. iii., page 104.

¶ "Étude sur la Lampe de Sûreté des Mineurs," by M. J. B. Marsaut, *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 323, and plate viii., fig. 3.

*Eloin Type.*

In the *lamp of M. V. Fumat** (1883) air was admitted below the glass through two vertical strips of gauze, the outer one of 1,296 apertures and the inner one of 784 apertures per square inch. Above the glass, inside the Eloin tube, was a slightly conical gauze cap, closed at the top by a short metal cap; the gauze contained 784 apertures per square inch. The air-inlet gauzes were shielded by a metal ring, which extended for a short distance above the height of the wick, and thus interfered with the downward direction of the light. M. Haton de la Goupillière† has described a form of this lamp, in which a conical-shaped gauze cap replaced the Eloin tube, thus forming a lamp with two gauze caps.

*The Buschmann lamp*‡ received its air below the glass through holes in a brass ring and gauze discs. Above the glass were two gauze caps, one inside the other, of true cone shape; these fitted inside a bonnet or tube of the shape of a truncated cone, prolonged upwards as a circular chimney.

*Mueseler Type (Unbonneted).*

The lamp invented by *Herr Rosenkrantz*,§ of Dortmund, had an internal chimney, the lower part of sheet-iron, the upper part a cylinder of gauze, of 710 apertures to the square inch, closed at the top by a circular piece of gauze; the outer gauze cap, of Boty type, had 930 apertures to the square inch. The sheet-iron portion of the chimney, which did not come below the glass, was bent inwards, thus contracting the exit of the products of combustion at the bottom of the chimney.

*The Barretta*‖ was a modified Mueseler, with air-feed from below the flame, the inlet being protected by a metal shield.

* An example of this lamp is in the collection of safety-lamps in the Science Museum, South Kensington. See also the *Final Report of the British Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 16.

† *Cours d'Exploitation des Mines*, 1885, vol. ii., page 530, section 1161.

‡ Prussian Firedamp Commission. *Schluss-Bericht der Lampen-Unter-Commission*, 1886, vol. iii., plate xl.

§ "Étude sur la Lampe de Sûreté des Mineurs," by M. J. B. Marsaut, *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 337, and fig. 6, plate ix.

‖ *Cours d'Exploitation des Mines*, by M. Haton de la Goupillière, 1885, vol. ii., page 529, section 1160.

The lamp had two gauze caps protected externally by a metal shield. The chimney was continued below the level of the top of the glass by a truncated cone of glass.

*Mueseler Type (Bonneted).*

*The Smethurst lamp** was tested by the Committee of the Midland Institute in 1884, and by the British Royal Commission of 1886.

*The Thomson No. 2 lamp*† had two concentric glasses (for safety, not for the inlet of air); a bonnet and a cylindrical gauze cap; and two chimneys, the outer one cylindrical, the inner one conical. The two chimneys were joined together at their bases, which were of the same diameter as the inner glass; they did not, however, rest upon this glass, but were joined to it by a vertical strip of gauze, which was intended to serve the same purpose as the gauze diaphragm in the Mueseler lamp.

The British Royal Commission of 1886 reported that "as a source of light it is very defective," and that the flame was easily extinguished by a slight inclination.

In *Saint's Improved Mueseler* the chimney was surrounded by a horizontal metal disc a short distance above the horizontal gauze diaphragm: air entered through inlet-holes just above the glass, and was prevented from rising into the gauze cap by this disc. In the direction of the chimney the under side of the metal disc terminated in a slightly conical flange, into which the chimney fitted. In the Report of the Prussian Sub-committee on Safety-lamps, the lamp was shown as unbonneted; but in the Report of the Midland Institute it was favourably mentioned as a bonneted lamp.

The interior of the *Routledge & Johnson No. 5 lamp*‡ resembled the Mueseler, without the horizontal gauze diaphragm; the outer portion resembled the Clanny, and was fitted with a shield extending up to the top of the gauze cap, the gauze cap being slightly conical. There were thus two gauze caps, one for the Mueseler

* *Final Report of the Royal Commission on Accidents in Mines*, 1886, appendix xxiv., fig. 30.

† *Ibid.*, fig. 27.

‡ *Ibid.*, fig. 28; *Transactions of the North of England Institute of Mining and Mechanical Engineers*, 1884-1885, vol. xxxiv., page 183, and plate xxxv

lamp inside, and one for the Clanny case. Air entered through the outer gauze cap below the shield, some of the feed-air passing down between two concentric glasses, and a vertical strip of gauze, to the flame; but air could also pass to the flame through the inner gauze cap, and through the space between the chimney and the inner glass left by the supports to the chimney. The products of combustion passed up the chimney, and out through the upper portion of the two gauze caps. The top of the lamp was covered by a dome, which, with the shield, practically formed a bonnet, in which air-exit holes were placed.

The British Royal Commission of 1886 recommended that the Mueseler lamp should be fitted with a ring of thin metal having a short vertical tube projecting downwards at its inner edge, somewhat less in diameter than the internal diameter of the glass; this ring was to be introduced below the horizontal gauze diaphragm and above the glass, in order to prevent gas, when ignited below the gauze diaphragm, from being in immediate contact with the glass. In this way the formation of cracks in the glass would be retarded, if not prevented.*

## XIV.—PERIOD 1888 TO 1913.

During this period two Government Commissions, the Austrian Firedamp Commission of 1885-1891 and the British Royal Commission on Mines of 1906, issued reports; while a considerable amount of investigation was carried out by Commissions and Committees working under Government direction, and by individuals. The testing of safety-lamps in France, commenced in connexion with the Firedamp Commission of 1878-1882, was continued, and in 1891 the Commission was made permanent. In 1900 it was decided to instal an apparatus for testing safety-lamps at the School of Mines, Paris. In Belgium a Government station for investigation into matters connected with the safety of explosives and of lamps was erected about 1902 at Frameries la Bouverie. In Great Britain a similar testing-station was established under the Home Office in 1912 at Eskmeals, near Barrow-in-Furness. The lamp-testing station at Aldwarke Main continued to be available for experimenting with safety-lamps, and in 1909 the University of Leeds† installed an

* *Final Report of the Royal Commission on Accidents in Mines*, 1886, page 84.

† *Trans. Inst. M. E.*, 1909-1910, vol. xxxviii., page 524.

apparatus for testing lamps, not only in horizontal and vertical currents, but also in currents ascending and descending at an angle of 45 degrees. The testing of lamps, and especially of internal relighters, attracted much attention in Germany, as installations erected for this object were mentioned at Bochum; at the Glückhilf-Friedenshoffnung Mine at Waldenburg, Silesia; at Neunkirchen; at Bismarck Colliery, near Gelsenkirchen; and at Derne, near Dortmund. In Saxony a testing-station was erected at Zwickau in 1908; in Austria the apparatus at Mährisch-Ostrau used by the Austrian Firedamp Commission of 1885-1891 appears to have been maintained, and experiments were conducted at Karwin. Tests on certain points relating to the safety-lamp have also been conducted by individuals in special forms of apparatus.

In Great Britain the accurate estimation of small quantities of firedamp by means of the safety-lamp attracted a great deal of attention.

An interesting feature of the period was the change in legislation relating to safety-lamps in Belgium and in Great Britain. In the former country, up to 1904, the Mueseler was the only lamp permitted for use in mines of the second and third categories, with certain exceptions which have been already pointed out; but in that year a complete alteration was made: the use of the unbonneted Mueseler was no longer sanctioned in mines of the second and third categories, while the principle was adopted of permitting lamps for use on the result of tests conducted at the Government testing-station. This principle was adopted in the Coal Mines Act of 1911 in Great Britain.

As Government regulations on the subject of safety-lamps must exercise a considerable influence on the types of lamp employed, and on their construction, an attempt has been made in this part of the paper to trace briefly the course of legislation relating to safety-lamps in France, Belgium, and Great Britain. But here a word of caution is necessary. Most legislative enactments on any subject contain a broad principle, which applies generally; but the operation of this principle may be extended to certain cases which it would not otherwise cover, while other cases may be exempted from its operation. As the object of the paper is simply to deal with such legislation in its bearing on the development of the safety-lamp, only the broad outlines have been noticed. The writers would also point out that the informa-

tion given respecting legislation has been obtained from the regulations published in the *Annales des Mines* (Paris) and in the *Annales des Mines de Belgique*; and although they have taken pains to trace the course of legislation accurately, it is quite possible that here and there some regulations may have escaped their notice. The same remark applies to the lists of "permitted" lamps; as is the case in Great Britain, so in France and in Belgium: the list is liable to alteration from time to time—new lamps may be added, and older forms withdrawn. Too much reliance, therefore, should not be placed on the information given under this head in the paper.

Considerable improvements have been made in the construction of lamps, so as to secure strength in the various parts, and to simplify the operations of cleaning and putting the lamps together. In Great Britain the bonnet or shield was extensively adopted. In 1913 of the 740,001* flame safety-lamps in use, exclusive of electric lamps, 96 per cent. were described as "shielded," while the lamps "permitted" under the safety-lamps Order of August 26th, 1913, were all bonneted. It is evident, however, that the preference shown to bonneted lamps was not due altogether to the operation of the Coal Mines Act of 1911, for in 1911 "shielded" lamps formed 95 per cent. of the total number of lamps in use. The Marsaut lamp was most generally employed, as 45 per cent. of the lamps in use in 1913 were classed as belonging to that type. It was followed closely by the Clanny with 41 per cent.; this number, however, included some lamps classed as "ordinary," which may mean the unbonneted Clanny. Only 4·7 per cent. of the lamps in use in 1913 were classed as Mueselers.

The lead rivet was most extensively used for locking lamps, 54 per cent. of the lamps being fitted with it, while 36 per cent. had magnetic locks. Of illuminants, colza, or colza and petroleum, were mostly used, 66 per cent. of the lamps being lighted by it; "volatile spirit" was used in 17 per cent. of the lamps, and petroleum in 8 per cent.

Nearly half the number of the lamps in use were arranged to be lighted by electricity.

A similar feeling in favour of bonneted lamps was shown in

* The figures given are taken from *Mines and Quarries: General Report, with Statistics for 1913*, by the Chief Inspector of Mines, part ii.—*Labour.*

Belgium and in France, since all the permitted lamps in both countries belonged to this class. Light mineral oils have also been sanctioned for use as illuminant. A point in which Continental practice differs from that established in Great Britain is to be found in the extensive use of internal relighters, of approved form, in Belgium, France, and Germany, a practice which does not appear to have commended itself to the British Royal Commission on Mines of 1906. In Great Britain a remarkable increase in the number of electric lamps in use at collieries is shown towards the end of the period. In 1911 only 4,298 of these lamps were in use, but in 1913 the number had risen to 37,823.

Several forms of lamp designed to use acetylene as an illuminant have been brought out*; M. Lemaire† has also given a description of a safety-lamp designed to burn the vapour of benzine mixed with air.

Among the new forms of safety-lamp introduced during this period the following may be mentioned:—

*The Howat Deflector lamp*‡ was a Marsaut with a special arrangement for deflecting the air entering the lamp. The inlet-holes were pierced vertically in the outer portion of the ring which carried the bonnet; but the air which entered through these holes was prevented from passing at once to the gauzes by a short metal cylinder which projected upwards for a small distance; this cylinder did not fit closely on the outer gauze, but a space intervened between them. A flanged ring prevented the entering air from rising too far into the lamp. The bonnet was removable, and was locked by a lead plug.

*The Ashworth-Hepplewhite-Gray*§ was similar to the Gray lamp, but it had three inlet-tubes in place of four. Near the base of two of the inlet-tubes were openings, one in each tube, through which air could enter; when not required, these openings could be closed by sliding shutters. The glass was made in the shape of a truncated cone, and was surmounted by a slightly

* A Wolf lamp of Marsaut type constructed to burn acetylene is in the collection of safety-lamps in the Science Museum, South Kensington.

† "Note sur une Lampe de Sûreté à Incandescence alimentée à la Benzine (Système Goulet)," by Emmanuel Lemaire, *Annales des Mines de Belgique*, 1911, vol. xvi., page 623.

‡ *Trans. Inst. M.E.*, 1889-1890, vol. i., page 260.

§ *Ibid.*, page 256: and 1902-1903, vol. xxv., page 64.

coned gauze cap, inside the Eloin tube, which was also placed immediately above the top of the glass. Air entered the lamp through the inlet-tubes near to the top of the lamp, and was conveyed by the tubes to an annular chamber below the wick-tube, the inner wall of which consisted of a strip of gauze. The products of combustion passed out through the top of the gauze cap, through a contracted opening in the top of the Eloin tube, and out through openings in a specially-constructed hood or cap at the top of the lamp.

A metal disc was placed on the lamp just above the inlets of the air-feed tubes, which was attached in such a way as to allow of its rotation through the width of the tubes. This disc could be made to act as a shut-off.

*The Ashworth-Gray** was a further modification of the Gray type of lamp, in which the upper part of the lamp above the glass was surrounded by a bonnet or casing: the air-inlet tubes did not extend to the top of the lamp, but commenced immediately below the bonnet. Inlet-holes for admission of air were cut in the lower part of the side of the bonnet; through these air passed into the bonnet, and thence into the air inlet-tubes, by which it was conducted to the flame.

The *Thomas Gray*† *lamp* (the Gray No. 2 of Mr. Ashworth) was a lamp with a single glass, conical metal chimney, slightly conical gauze cap, and a bonnet. Air was supplied to the flame through four tubes, which commenced in the bottom of a hollow ring close to the base of the bonnet. Air entered the lamp through openings in the bonnet situated near to its base, and passed into the air-inlet tubes, by which it was conducted into an annular chamber below the wick-tube, guarded on the inside by wire gauze. The products of combustion rose up into the chimney and into the upper portion of the gauze cap (which was outside the chimney), and were discharged through holes cut in the upper part of the bonnet. The chimney commenced at the top of the glass, its lower diameter being the same as the interior diameter of the glass, on which it rested; it was of the shape of a truncated cone, with the smaller end upwards, and extended high up into the gauze cap. The inlet and outlet

* *Trans. Inst. M.E.*, 1902-1903, vol. xxv., page 64.

† *Ibid.*, pages 66 and 68; and *Annales des Mines*, 1912, series 11, vol. i., *part. adm.*, page 197.

openings were guarded with a "deflector" arrangement, so that air could only enter tangentially to the surface of the gauze.

In order to enable the presence of firedamp to be detected in places situated above the point of inlet of air to the lamp, arrangements were made to lengthen one of the tubes by the addition to it of another, or lengthening, tube, which extended well above the top of the lamp.

*The lamp of M. Cambessédès,** of Douai, was a kind of bonneted Mueseler, with a short chimney, and air-feed from below the flame. The oil-reservoir was placed at one side of the lamp, and acted as a reflector. Air was admitted on a level with the bottom of the bonnet through tubes, down which it passed to the flame. The products of combustion rose up through a short chimney into a gauze cap and out through holes in the top of the bonnet.

*The "Lampe á Rondelles"*† (lamp with flat iron rings) was described by the French Sub-commission on Safety-lamps in 1892 as a Boty, in which the gauze cap was replaced by a cylinder formed of flat rings of iron placed one above the other, and maintained at a distance of 1 millimetre (0·04 inch) apart.

*The Thorneburry*‡ was a bonneted chimney-lamp, with two concentric glasses. Inside the bonnet was a long gauze cap; the chimney, which tapered upwards, was of the same diameter at the bottom as the inner glass on which it rested. Air entered the lamp through vertical holes in the ring at the bottom of the bonnet, passed through a strip of gauze or perforated plate, and through the bottom of the gauze cap. It then passed through a strip of gauze into the space between the glasses and through another gauze ring at the bottom of the glasses to the flame. The products of combustion rose up through the inner glass into the chimney, and thence through the upper end of the gauze cap into the bonnet, in which holes were cut to admit of their discharge.

*Barns's lamp*§ (1894) was a bonneted chimney lamp. Air entered through holes in the lower part of the bonnet and passed

* *Annales des Mines*, 1892, series 9, vol. i., page 50.

† *Ibid.*

‡ *Trans. Inst. M.E.*, 1891-1892, vol. iii., page 226.

§ An example of this lamp is in the collection of safety-lamps in the Science Museum South Kensington

down three tubes to a chamber below the wick-tube, the interior of which was guarded by a ring of gauze. The metal chimney was protected by a gauze cap.

In the *Fumat lamp* (Fig. 37)* the flame was surrounded by a glass cylinder. On the top of the glass was a cylindrical metal chimney, slightly less in diameter than the internal diameter of the glass on which it rested by means of a metal ring fitted with a flange; near the top of the chimney the metal was cut away all round the chimney, and the space so formed was filled in with wire gauze; the top of the chimney was closed by a metal cap, and the base of the chimney extended a short distance below the top of the glass cylinder. The chimney was enclosed in a bonnet, on one side of which and near to its base inlet-holes were cut, the outlet-holes being situated near to the top of the bonnet. The bonnet was connected with the lower part of the lamp by standards, and by a vertical air-feed channel, which surrounded part of the glass cylinder, and was situated on the opposite side of the lamp to the air-inlet holes in the bonnet.

FIG. 37.—FUMAT LAMP.

Reproduced by permission of the Authorities from a lamp (received in 1904) in the collection of the Science Museum, South Kensington.

Air entered the lamp through the openings in the lower part of the front of the bonnet, and passed through the vertical air-feed channel into an annular chamber below the wick-tube; the inner side of this chamber was protected by two strips of gauze. The air passed through these gauze strips to the flame. The products of combustion rose into the cylindrical chimney,

* *Annales des Mines de Belgique*, 1904, vol. ix., pages 1124 and 1368; *Annales des Mines*, 1912, series 11, vol. i., *part adm.*, pages 191-200.

and passed out through the ring of gauze high up in the chimney and through holes cut in the upper part of the bonnet.

There appear to have been several varieties of this lamp.

The French "Arrêté Ministériel" of February 23rd, 1912, authorized the use of five of them, the "Modèle de 1895," "Modèle G.C.," and "Modèle réduit de 1903," all of them constructed to burn oil; the "Modèle de 1895" and "Modèle réduit de 1906" burned light mineral oil ("essence"). These seem to have resembled one another in general form, differing only in details; for example, in the first two the inlet and outlet of air appears to have been through short horizontal tubes attached to the air-inlet holes on the inside of the bonnet. The "Modèle réduit de 1903" is the one described in the Belgian "Arrêté Ministériel" of August 19th, 1904.

*The Body-Firket** was a bonneted lamp with a chimney, resembling in some respects the bonneted Mueseler type. The air-inlet was through vertical holes in a portion of the ring below the bonnet; from the bonnet the air passed to an annular chamber below the wick-tube through an enlarged flattened tube or air-channel, which connected the bonnet with the ring below the glass. This air-channel was situated on the opposite side of the bonnet to the air-inlet holes; the annular air-space below the wick-tube was guarded on the inside by a metal ring, in which openings were cut, and above this ring was a horizontal disc of gauze; the air after passing through this gauze was directed on to the flame by a metal cone. The chimney, which was slightly conical, with the smaller end upwards, was fitted on the top of the glass by means of a metal collar with an external flange, which surrounded the outside of the top of the glass; air could not pass through this collar, which prevented its passage direct to the flame and caused it to pass into the air-channel: the lower extremity of the chimney was smaller in diameter than the glass. The chimney was surrounded by a slightly conical gauze cap, which was somewhat larger in diameter at its base than the interior diameter of the glass; the base of the gauze cap was guarded by a short metal ring. Outlet-holes for the products of combustion were cut in the upper part of the bonnet.

* *Annales des Mines de Belgique*, 1904, vol. ix., pages 1138 and 1370.

*The "Sight" lamp** (1889) was a bonneted Clanny. The gauze was protected by a glass, and the bonnet had wide slots cut in it so as to enable the gauze and glass to be seen. Another form of "Sight" lamp* (1891) for fire-triers was of the Eloin type. The Eloin tube was replaced by a glass cylinder protected by a metal case, in which wide slots were cut so that the interior of the lamp could be seen. The lamp had a cowl of glass. Air entered the lamp through three apertures in the ring below the flame, guarded by wire gauze, and passed into an annular chamber below the flame.

About 1892 the firm of *Friemann & Wolf*†† introduced a special form of bonnet with corrugations, and slots for the admission of air.

*The Louvre lamp*‡‡ (1898) of G. A. Meyer was a Marsaut lamp with a double bonnet, the inner bonnet being fixed, while the outer one could be turned horizontally. Both bonnets were pierced with slots, and there was a space between them. When the slots in the two bonnets were opposite each other, the gauzes could be seen, and air had free access to the lamp: when the outer bonnet was so turned as to close the slots, the air-supply was restricted.

*The "cuirasse de Gennes,"* which the French "Arrêté Ministériel" of February 23rd, 1912, permitted for optional use with the Marsaut lamp, was a bonnet formed of three metal plates fastened at the top and at the bottom, and so arranged as to leave a space of 6 millimetres (nearly ¼ inch) between them. One side of each plate, however, was bent back, and then carried forward so as to protect the opening between it and the next plate, and yet to leave a space for the air to pass through. Consequently, air entered tangentially to the surface of the gauze, and did not strike directly upon it. No other means of ingress or egress was afforded to the air except through these slits.§

The *Hailwood lamp* (Figs. 38 and 39) was described in a paper by Mr. E. A. Hailwood on "Miners' Electric Lamps Compared

* An example of this lamp is in the collection of safety-lamps at the Science Museum, South Kensington.

† *Die Entwickelung des Niederrheinisch-Westfälischen Steinkohlen-Berghaues in der zweiten Hälfte des 19ten Jahrhunderts*, vol. vii., page 245, and fig. 180.

‡ *Ibid.*, page 247, and fig. 181.

§ *Annales des Mines*, 1912, series 11, vol. i., page 190.

with the Combustion-tube Oil-lamp"* as a bonneted lamp, which might be either of the Marsaut or the Mueseler type—that is to say, it might be fitted either with two gauze caps, or with one gauze cap and a horizontal diaphragm of gauze. In either case a combustion-tube was fitted to the lamp. This consisted of a metal chimney, which rose from the level of the top of the glass high into the gauze cylinder, the chimney being protected at the top by a metal plate. The lower part of the chimney was fitted with a metal holder, into which was inserted a glass tube, which formed a continuation of the chimney downwards to a short distance above the wick-tube. The inlet of air to the lamp was through the usual openings at the bottom of the bonnet, and air passed to the flame through the space between the outer glass cylinder and the inner glass combustion-tube.

FIG. 38.—PARTS OF THE HAILWOOD LAMP.
Reproduced from blocks lent by Mr. E. A. Hailwood.

A number of lamps also were brought out which may be described either as Marsaut lamps with entrance of air below the flame, or as bonneted Boty lamps with two gauzes and protected air-inlet. They differed from one another chiefly in the method adopted for taking in air and in guarding the inlet. Only two lamps of this class were "permitted" in Great Britain by the Safety-lamps Order of August 26th, 1913—one for general

* *Trans. Inst. M.E.*, 1914-1915, vol. xlviii., page 215.

use, the other for use by officials only—and in these the under air-feed appears to have been optional. A number of these lamps, however, appear to have been authorized in Belgium. The following lamps diverged somewhat from the general type:—

*The Wolf No. 3* or *Wolf-Joris* had two concentric glasses, and the bonnet was of a special shape, being contracted a short distance above the base, instead of the usual cylindrical or slightly conical form.

FIG. 39.—HAILWOOD LAMP.

*The Demeure lamp* was of the usual type with bonnet, two gauzes, and under air-feed, but in one form* of the lamp there was a window in the bonnet, which could be closed by a sliding shutter.

The following lamps were designed especially for the purpose of indicating small percentages of firedamp:—

In the *Chesneau lamp* methyl-alcohol was used as the fuel; only a small quantity of cotton was placed at the base of the wick-tube inside the reservoir to prevent the escape of the alcohol in case the lamp was upset. The wick, which was circular, was raised or lowered by means of a pin cut with a screw-thread, which was worked by a thumbscrew placed under the bottom of the alcohol reservoir.

On the top of the reservoir was situated a metal ring, in which openings were cut, guarded by a double thickness of metal gauze, and the inlet of air took place through this. Around the flame was a short metal cylinder, serving as a shield; and from the top of this cylinder rose the gauze cap, which was slightly conical; this gauze was guarded by a cylindrical bonnet, the bottom of which carried a flange, by means

* *Annales des Mines de Belgique*, 1906, vol. xi., page 1167.

of which it made an airtight connexion with the metal cylinder (which surrounded the flame) on which it rested. A window was cut in the bonnet so as to allow of observation of the flame-caps, this window being protected by a plate of mica. Two auxiliary movable shields, one towards the bottom of the bonnet, and one over the air-inlet holes, were added for additional safety. Methyl-alcohol, in which was dissolved 1 gramme of cupric nitrate and 1 gramme of ethylene chloride, was used instead of alcohol.*

*The Clowes lamp*†—invented by Prof. Frank Clowes of University College, Nottingham—was an Ashworth-Gray lamp, burning oil, to which could be fitted a cylinder containing hydrogen gas. In testing for small quantities of firedamp the hydrogen was admitted to the lamp and the oil-flame extinguished: the hydrogen could then burn at the top of a copper tube, by which it was conducted into the lamp, and the height of the flame could be regulated by a valve. A scale was affixed to facilitate the reading. It was claimed that as little as ¼ per cent. of firedamp could be detected by this lamp.

*The Stokes lamp*‡—invented by Mr. A. H. Stokes, H.M. Inspector of Mines—was an Ashworth-Hepplewhite-Gray, burning oil. A small tube passed through the oil-vessel, terminating in a spring-cap level with the wick-tube; below, the tube opened into a circular cavity in the bottom of the oil-vessel. An alcohol tester, consisting of a cylindrical metal vessel containing alcohol, fitted with a long narrow wick-tube, could be inserted into the small tube previously mentioned. When the alcohol tester was not in use, the circular cavity in the bottom of the oil-vessel was closed by a screwed plug. The lamp was said to indicate down to 0·5 per cent. of firedamp.

*The Ashworth-Gray tri-wick alcohol or petroleum gas-testing safety-lamp* was of the Ashworth-Gray type, fitted with three wicks. Air entered through holes in the front part of the bonnet, and was conducted to a chamber around the flame

* *La Sécurité dans les Mines*, by M. H. Schmerber, 1910; and "Note sur un Nouvel Indicateur de Grisou," by M. G. Chesneau, *Annales des Mines*, 1892, series 9, vol. ii., page 203; *ibid.*, 1912, series 11, vol. i., page 185. An illustration of the lamp is shown in a paper on "The Gray type of Safety-lamp," by Mr. James Ashworth, *Trans. Inst. M.E.*, 1902-1903, vol. xxv., fig. 14, page 69.

† *Trans. Inst. M.E.*, 1893-1894, vol. vii., page 2.

‡ *Ibid.*, 1892-1893, vol. v., page 462.

through a single flat enlarged tube or air-conduit placed at the back of the lamp.*

The following firedamp indicators could be fitted to any type of lamp:—

*The Beard-Mackie* indicator consisted of a small frame fixed over the flame of the lamp. On this frame were fixed six platinum wires, each of which glowed according to the percentage of firedamp present.†

*The Cunynghame-Cadman* indicator consisted of a piece of asbestos impregnated with a salt, which imparted a colour to the flame-cap, and so, in the case of small percentages of firedamp, made the cap more easily visible.‡

*The Briggs loop* was a loop of copper wire which could be placed across the flame of the lamp.§

In 1890 the Austrian Firedamp Commission‖, appointed on June 11th, 1885, published an account of the trials made by them with various forms of safety-lamp, and their final Report appeared in 1891.

The lamps tested appear to have been—the Mueseler,¶ Belgian, English and Ostrau types; Wolf benzine lamps;¶ the Marsaut; Howat (deflector type); Morgan; Cambessédès; and Pieler.

The experiments were made at Mährisch-Ostrau with natural firedamp, in atmospheres of explosive mixture at rest and in motion. The apparatus used for testing lamps in currents of explosive mixture was of the trough form, and was designed by Dr. Schondorff, but the oil-vessel of the lamp under investigation appears to have been excluded. A chamber of special construction was used for the experiments in still atmospheres.

The Commission did not consider it necessary to prescribe any particular type of lamp, and reported that the Mueseler, Wolf

* *Trans. Inst. M.E.*, 1902-1903, vol. xxv., page 68.

† *Ibid.*, 1903-1904, vol. xxvi., page 214.

‡ *Ibid.*, 1909-1910, vol. xxxix., page 13.

§ *Ibid.*, 1911-1912, vol. xliii., page 64.

‖ Verhandlungen des Central-Komites der Oesterreichischen Commission zur Ermittlung der zweckmässigsten Sicherheitsmassregeln gegen die Explosion Schlagender Wetter in Bergwerken, part iv.; and *Trans. Inst. M.E.*, 1891-1892, vol. iii., page 531.

¶ The only Mueseler lamp illustrated was the Ostrau form, which was shown without a bonnet. The Wolf was shown as an unbonneted lamp with two gauze caps. Some tests, however, were made on Wolf lamps with one gauze cap.

(with two gauzes), and Marsaut lamps had stood satisfactorily the tests applied to them; so satisfactory had these trials been that the Commission considered it unnecessary to examine any other means of illumination, such as the electric light.

They recommended that all lamps of any particular type should be made alike, and they laid down the dimensions to which the Mueseler, Wolf, and Marsaut lamps should conform. Various recommendations were also made as to the use of safety-lamps in fiery mines, and the employment (when permitted) of "mixed lights."

In 1900 Messrs. Mayer & Daum used the apparatus at Mährisch-Ostrau for further experiments.*

In 1896 in Great Britain an Act of Parliament was passed to amend the Coal Mines Regulation Act of 1887. Section 5 required that safety-lamps should be provided by the owner of the mine; and that no portion of any safety-lamp should be removed from the mine while the lamp was in use.

The British Royal Commission on Mines, appointed on June 7th, 1906, included safety-lamps among the subjects of its Report, but did not conduct any tests on lamps. In the Second Report of the Commission† various questions relating to safety-lamps, and the position as to the compulsory use of safety-lamps under the Coal Mines Regulation Acts of 1887 and 1896, were discussed generally. The subject of official testing of safety-lamps was also brought forward, and a recommendation was made that a Government testing-station should be established, that a list of permitted safety-lamps should be drawn up by the Secretary of State, and that where the use of safety-lamps was prescribed, only lamps on the permitted list should be employed. Suggestions were also made as to the examination and lighting of safety-lamps.

The Coal Mines Act of 1911 laid down in Sections 32, 33, and 34 provisions as to the use of safety-lamps under certain conditions, and in certain places, and as to the construction and examination of safety-lamps. Section 33 provided that wherever safety-lamps were required by the Act or by the regulations of the mine to be used, no safety-lamp should, after January 1st, 1913, be used by any person employed in the mine, unless it was

* *Annales des Mines de Belgique*, 1904, vol. ix., page 969.

† July, 1909, page 129.

provided by the owner of the mine, and was of a type for the time being approved, "as respects the class of mines to which the mine belongs," by the Secretary of State.

A safety-lamp testing-station was erected at Eskmeals, near Barrow-in-Furness, which was described in a Report of the Departmental Committee on the Testing of Miners' Safety-lamps, issued in 1912. It comprised—

(1) The lamp-testing gallery in which lamps were tested in currents of explosive mixtures of gas and air.

(2) A chamber in which lamps were tested in still atmospheres of gas and air.

(3) A photometer for determining the illuminating power of the lamps tested.

(4) Devices for submitting the lamps, or portions of them, to tests for mechanical strength.

A gas-holder of 1,500 cubic feet capacity was provided for supplying gas to the testing apparatus, arranged so that any kind of gas might be used. Petrol-vapour and coal-gas were mentioned in the Report as having been employed. The lamps were submitted to mechanical and photometric tests, and to tests in an explosive mixture—both at rest and in motion. In addition to tests made for the purposes of the Coal Mines Act, some experimental work has also been undertaken.*

In pursuance of Section 33 of the Coal Mines Act of 1911, Safety-lamp Orders are from time to time issued, giving the name and a description of each safety-lamp "permitted" for use under the Act. With two exceptions, all the lamps permitted up to the end of 1913 were of the Marsaut or bonneted Mueseler type. The two exceptions were lamps of the Marsaut type which derived their air from below the flame.

In 1902 a testing-station was erected by the Belgian Government at Frameries la Bouverie.† The experiments were conducted by MM. V. Watteyne and S. Stassart. The apparatus was of the covered-trough type, fitted with adjuncts to allow of the lamps being tested, not only in horizontal currents of explosive mixture, but also in currents ascending or descending

* *Mines and Quarries: General Report, with Statistics, for 1913*, by the Chief Inspector of Mines, part ii.—*Labour*, page 75.

† *Annales des Mines de Belgique*, 1902, vol. vii., pages 993 and 1085; *ibid.*, 1904, vol. ix., page 149.

vertically or at various angles. Natural firedamp* piped to the surface from the No. 3 Pit of the Agrappe Colliery of the Compagnie des Charbonnages Belges was used.

The results of these investigations were published in a paper by MM. V. Watteyne and S. Stassart in 1904.† The paper commenced with an interesting summary of the principal enquiries into the safety-lamp since 1840, and then proceeded to deal particularly with the following points:—

(1) Whether it was advisable that safety-lamps should burn only pure vegetable oil.

(2) The advisability of using re-lighters.

(3) Tests on various kinds of safety-lamp, and the question of the exclusive use of the Mueseler lamp, which up to the time of these enquiries had been considered in Belgium "la lampe de sûreté par excellence."

The lamps tested were as follows:—

Unbonneted: The Davy; "lampe de porion à simple toile," "lampe de porion à double toile"; Mueseler.

Bonneted: The Marsaut; Wolf lamp, burning benzine, with air-inlet above the flame; Wolf lamp, burning benzine, with air-inlet below the flame; Mueseler; Fumat; Body-Firket.

The conclusions reached were that, except in the case of the Mueseler lamp, the conditions of safety of the lamps examined were practically the same whether benzine or oil was employed. Re-lighters using phosphorus, fired by friction, offered no source of danger; but re-lighters could not be used with the Mueseler lamp, as they practically converted it into a single-gauze lamp.‡

The tests on safety-lamps confirmed the opinion expressed by previous experimenters as to the value of the bonnet, and as to the safety of the unbonneted Mueseler lamp. This lamp, except in three experiments, resisted horizontal currents passing at velocities up to 20 metres (65½ feet) per second and containing 7, 8, and 9 per cent. of firedamp; but with ascending and descending currents it passed flame at lower velocities. The behaviour

* 7 to 9 per cent. appears to have been the proportion generally used in the experiments, and this MM. Watteyne and Stassart seem to have found most dangerous. In some cases, however, the limits were extended to 6 and 10 per cent. (see *Annales des Mines de Belgique*, 1904, vol. ix., page 987).

† "Expériences sur les Lampes de Sûreté," by V. Watteyne and S. Stassart, *Annales des Mines de Belgique*, 1904, vol. ix., page 947.

‡ *Ibid.*, page 1060.

of the lamp was worst in ascending currents, apparently owing to a reversal of the action of the lamp.*

The bonneted lamps appear to have passed the tests satisfactorily. The bonneted Mueseler lamp was affected by vertical descending currents, but this only began at "considerable velocities."

Experiments were also made on the influence of coal-dust on the safety of lamps. Lamps of types which had already been tested when new were tested again after they had been in use, in order to ascertain the effect produced by wear. Evidence from officials and workmen as to the behaviour of the various lamps in the pit was also taken.

The large Mueseler and Wolf lamps with under air-feed for "chargeages" were tested.

Investigations were conducted into the safety of the various materials used in making gauzes, and photometric tests were carried out.

The results of these investigations were shown in Belgium by an "Arrêté Royal" of August 9th, 1904,† which related to the lighting of coal-mines. Regulations were laid down relative to the lighting of coal-mines not containing firedamp ("mines sans grisou"), and of mines containing firedamp ("mines à grisou"); respecting the provision of safety-lamps of approved type; the locking, care, and cleaning of safety-lamps; the issue of lamps to the workmen and responsibility for them; the relighting of lamps in the pit; and other provisions of similar nature. Articles 43 to 49 of the "Arrêté Royal" of April 28th, 1884, were annulled. On August 19th, 1904, an "Arrêté Ministériel"‡ was issued, containing certain regulations respecting safety-lamps, from which the following notes have been extracted:—

Article 1: The following lamps were admitted for lighting all mines containing firedamp ("mines à grisou"):—Bonneted Mueseler; Marsaut; Wolf with over air-feed ("à alimentation supérieure—lampe Marsaut à benzine"); Wolf with under air-feed ("à alimentation inférieure"); Fumat ("modèle réduit de 1903"), burning oil; Body-Firket, burning oil.

* *Annales des Mines de Belgique*, 1904, vol. ix., pages 1078 and 1081.

† *Ibid.*, page 1357.

‡ *Ibid.*, page 1360.

Article 2: Such lamps were to conform to the regulations annexed to the "Arrêté."

Article 3: In mines containing firedamp of the first category, the bonnet was not obligatory for the four first-mentioned types of lamp.

Article 4: In mines containing firedamp of the first and second categories, the lighting of the "chargeages" not situated in the return air-current could be effected by large lamps ("de grand format") of the following types:—Mueseler; Marsaut, with over air-feed;* and Wolf, with under air-feed, provided that they complied with the regulations annexed.

To the "Arrêté Ministériel" was appended a complete description and an illustration of each lamp, and any special provision as to its construction or use. For example, the Mueseler was not to be fitted with a re-lighter ("dispositif de rallumage").

The list of lamps authorized for use does not appear to have been fixed and invariable, but allowed of the subsequent addition of such lamps as satisfied the tests imposed and were authorized by an "Arrêté Ministériel" of the Minister of Industry and Labour ("le Ministre de l'Industrie et du Travail"). So far as the writers have been able to ascertain, the list of lamps permitted in Belgium up to August 5th, 1912, was as follows:—

Various types: Bonneted Mueseler;† Fumat, Modèle réduit de 1903†; Body-Firket.†

Marsaut type: Marsaut;† Wolf with over air-feed† ("à alimentation supérieure"), fitted with a phosphorus re-lighter and burning benzine.

Similar to the Marsaut, but with air-feed from below the glass—all fitted with a phosphorus re-lighter and burning benzine —Wolf with under air-feed† ("à alimentation inférieure"); Mulkay No. 1;‡ lampe de Bochum;§ lampe d'Arras;§ Mulkay No. 2;§ Grümer et Grimberg;§ Koch;§ Wolf No. 3 or Wolf-

* In the detailed description both the Marsaut and the Wolf with over air-feed were mentioned.

† "Arrêté Ministériel," of August 19th, 1904, *Annales des Mines de Belgique*, 1904, vol. ix., page 1360.

‡ *Ibid.*, April 7th, 1905; *ibid.*, 1905, vol. x., page 773.

§ *Ibid.*, November 9th, 1906; *ibid.*, 1906, vol. xi., page 1248.

Joris;* Müller† ("Grümer et Grimberg, Bochum"); André-Billon,‡ Seippel No. 6§ (replacing Seippel No. 2‖); Demeure No. 2¶ (replacing Demeure*); Dufrane-Castiau;** Wolf-Joris No. 4.††

The writers have been unable to ascertain the relative amount of favour shown to these various lamps in recent years; but, in a report dated September, 1907,‡‡ it was stated that at that time the Mueseler was the lamp most used in Belgium, the Marsaut and the Wolf burning benzine coming next. Also the great increase in safety given to safety-lamps by the adoption of the bonnet was mentioned.

In France the work of the Firedamp Commission, instituted on February 12th, 1887, was continued,§§ and M. Aguillon reported on it on September 30th, 1889; while M. Le Chatelier gave an account of the proceedings of the Commission at the International Congress of Mining and Metallurgy held in Paris in 1889.‖‖ No special type of lamp was recommended by the Commission, but the dangers presented by some of the existing types were indicated. A result was the prohibition by a "Circulaire Ministérielle" of August 8th, 1889, of lamps with short and wide chimneys, known as "Mueseler bâtardes."¶¶

In 1890 it was decided to instal a laboratory for testing lamps at the School of Mines, Paris. The installation included a plant for generating methane, with a gasholder of 6 cubic

* "Arrêté Ministériel," of November 9th, 1906; *ibid.*, 1906, vol. xi., page 1248.

† *Ibid.*, October 26th, 1908; *ibid.*, 1909, vol. xiv., page 453.

‡ *Ibid.*, January 14th, 1909; *ibid.*, page 459.

§ *Ibid.*, August 18th, 1909; *ibid.*, page 1615.

‖ See note ‡ on previous page.

¶ *Ibid.*, August 17th, 1910; *ibid.*, 1910, vol. xv., page 1868.

** *Ibid.*, June 8th, 1911; *ibid.*, 1911, vol. xvi., page 767.

†† *Ibid.*, August 5th, 1912; *ibid.*, 1912, vol. xvii., page 825.

‡‡ *Annales des Mines de Belgique*, 1907, vol. xii., page 1076.

§§ "Commission du Grisou: Note sur les Travaux de la Commission du Grisou de 1887 à 1900," by M. G. Chesneau, Ingénieur en Chef des Mines, Secrétaire de la Commission, *Annales des Mines*, 1900, series 9, vol. xvii., page 621.

‖‖ *Bulletin de la Société de l'Industrie Minérale*, 1889, series 3, vol. iii., page 575.

¶¶ The French Government appears to have possessed a power of direction or permission as to the safety-lamps that could be used. For example, when M. Marsaut wished to use the Mueseler safety-lamp at Bessèges in 1861, he applied for Government sanction to do so, and permission was granted by a prefectorial Order of September 24th, 1861 (See "Étude sur la Lampe de Sûreté des Mineurs," *Bulletin de la Société de l'Industrie Minérale*, 1883, series 2, vol. xii., page 321).

metres (212 cubic feet) capacity; an apparatus for testing the behaviour of lamps in currents of explosive mixture (methane and air) moving at a very low velocity, so arranged that, if necessary, a test could be continued for some hours; and an apparatus for testing lamps in explosive currents of high velocity, lighting-gas being used in this case. The current was produced by a fan; the lamps could be tested in currents directed on to them at an angle, and could be agitated in any direction.*

On February 4th, 1891, the Commission was made permanent, and in that year an important series of tests was carried out.† These showed particularly the importance of the part played by bonnets ("cuirasses complètes") on the safety of lamps, especially of the Marsaut and Fumat; both these lamps were found to give very satisfactory results. On the other hand, lamps the gauzes of which could be traversed by high-velocity currents of explosive mixture, even over a small area, allowed of the passage of flame.

Later on newer types of lamps were examined, and experiments were conducted on lamps fitted with re-lighters, and lamps burning light mineral oil ("à essence"). Portable electric lamps were also tested. The installation seems, in fact, to have become a permanent testing-station, to which eventually safety-lamps were referred by the Minister of Public Works ("le Ministre des Travaux Publics, des Postes, et des Télégraphes"), with the view of ascertaining whether they could be "permitted" for use underground or not. For example on April 25th, 1893,‡ a "Circulaire Ministerielle" was issued recommending M. Chesneau's firedamp indicator, and requiring that the use of dangerous forms of firedamp indicators should be discontinued.

On July 25th, 1895, a "Projet de Décret et Projet de Règlement-type sur la Police des Mines"§ was presented by the "Commission des Règlements des Mines" to the higher Administration, under which mines containing firedamp ("mines à grisou") were divided into two classes, namely, those which distinctly contained firedamp ("franchement grisouteuses") and those which contained little firedamp ("faiblement grisou-

* *Annales des Mines*, 1892, series 9, vol. i., page 47; *ibid.*, 1900, series 9, vol. xvii., page 621.

† "Expériences sur les Lampes de Sûreté," *Annales des Mines*, 1892, series 9, vol. i., page 47.

‡ *Ibid.*, 1893, series 9, vol. iii., *part. adm.*, page 254.

§ *Ibid.*, 1895, series 9, vol. viii. *part. adm.*, page 345.

teuses "). In mines that contained firedamp, only such safety-lamps as were contained in the Schedule A annexed were to be used, without prejudice to lamps which might be admitted later. The lamps described in the schedule were the Mueseler, the Marsaut, and the Fumat. In 1897* the Commission examined the question of authorizing lamps of the Marsaut and Mueseler types constructed to burn light mineral oil; they also tested certain forms of re-lighter, and in 1901† they reported on the Wolf lamp of Marsaut type with admission of air below the flame, burning benzine, and provided with a friction re-lighter.

On January 9th, 1903,‡ a "Circulaire Ministérielle" was issued permitting the use of the Chesneau firedamp indicator, and allowing the Marsaut, Mueseler, and Fumat lamps to be transformed into lamps burning light mineral oil under certain conditions; the Wolf lamp of Marsaut type with under air-feed was also permitted. Re-lighters of approved type were sanctioned. Subsequently permission was given for the use of the Marsaut§; Fumat§ (burning light mineral oil); and of the Wolf§; Wolf type d'Arras§; Mulkay§; and Bochum§ (type B) lamps, which were similar to the Marsaut, but with admission of air below the flame, burning light mineral oil. All these lamps could be fitted with an approved re-lighter. The lamp Müller‖, burning benzine (with a phosphorus re-lighter and automatic extinction), and the Fumat, modèle G.C.,¶ burning oil, were also permitted.

On August 13th, 1911, a "Règlement Général" relative to the working of mines of combustible substances** was issued, which included, among many other matters, the subject of safety-lamps. By Article 119 mines containing firedamp ("les mines à grisou") were divided into two classes, namely, "distinctly

* *Annales des Mines*, 1897, series 9, vol. xi., *Mémoires*, page 250.

†*Ibid.*, 1901, series 9, vol. xx., *Mémoires*, page 493.

‡ *Ibid.*, 1903, series 10, vol. iii., *part. adm.*, page 7.

§ *Ibid.*, 1907, vol. xii., *part. adm.*, page 318.

‖ *Ibid.*, 1908, vol. xiv., *part. adm.*, pages 480 and 676.

¶ *Ibid.*, 1911, vol. xix., *part. adm.*, page 330.

** "Règlement Général sur l'Exploitation des Mines de Combustibles," *Annales des Mines*, 1911, series 10, vol. xx., *part. adm.*, page 484 (there are two pages 484 in the *Partie Administrative* of this volume: the reference is to the second); translated in *Mines and Quarries, General Report with Statistics for* 1911, by the Chief Inspector of Mines, part ii.—Labour, page 151. In this "mines de combustibles" is translated as "coal-mines."

fiery "* (" franchement grisouteuses ") and " slightly fiery "* (" faiblement grisouteuses "). Article 141 divided mines working combustible substances into three categories, according to the degree of danger which arose from the presence of dust in them. In both cases (firedamp and dust) the classification was to be made by a local authority or board, the composition of which was defined. By Article 144 safety-lamps alone were allowed in mines containing firedamp (" mines grisouteuses "); in dusty mines (" mines poussiéreuses ") of the first category; and in places which were suspected under Article 131, such as workings approaching areas not well known, or which were known to be dangerous. Lamps with protected flame† could be used in the downcast shaft and its insets, but not in mines liable to sudden outbursts of firedamp. Article 146 required that safety-lamps should be of a type approved by the Minister of Public Works.

Other Articles dealt with the lighting of mines not containing firedamp (" mines non grisouteuses "), and with matters of detail respecting the construction, locking, care, and cleaning of lamps; the issue of lamps to the workmen; the re-lighting of lamps, etc.

This " Règlement Général " was followed by an " Arrêté Ministériel " of February 23rd, 1912,‡ by which firedamp indicators of the Chesneau type were authorized for use in mines containing firedamp (" mines grisouteuses "). Another " Arrêté Ministériel " was issued on February 23rd, 1912,§ by which the following safety-lamps were permitted under Article 146 of the " Règlement Général " of August 13th, 1911 :—

A.—Flame Safety-lamps.

Marsaut, burning oil.
Fumat, burning oil, 1895 model.
Fumat, burning oil, G.C. model.
Fumat, burning oil, reduced model of 1903.
Thomas Gray, burning heavy mineral oil.
Marsaut, burning light mineral oil (" à essence ").

* The writers have adopted the translation alluded to in the previous footnote.

† " Lampes à flamme protégée." These were lamps in which the flame was protected by glass and gauze, so as to avoid the risk of fire.

‡ *Annales des Mines*, 1912, series 11, vol. i., *part. adm.*, page 183.

§ *Ibid.*, page 186.

Fumat, burning light mineral oil, 1895 model.
Fumat, burning light mineral oil, reduced model of 1906.
Wolf, burning light mineral oil, with air-feed below the flame.
D'Arras, burning light mineral oil.
Müller, burning light mineral oil.

The lamps burning light mineral oil could be fitted with an approved internal igniter.

B.—Five electric lamps were permitted, which it is unnecessary to specify here.

A drawing and complete description of each lamp was given.

A permanent committee on firedamp and on explosives was constituted on March 2nd, 1912.*

The writers have been unable to ascertain what has been the position of the safety-lamp in Germany in recent years. Berginspektor Fähndrich and Bergassessor Beyling,† referring to the year 1899, stated that in the Ruhr district 184,000 safety-lamps were in use, of which 38,000 burned oil and 146,000 benzine; only 7,500 safety-lamps were not fitted with an internal igniter. The lamps were mostly of the Boty type, and differed in respect of small variations in the parts of which they were composed, also in the methods adopted for locking, and especially for relighting, which necessitated different arrangements in the interior of the lamp. Most of the lamps mentioned appear to have had one gauze only, although some had two, and were supplied with air from above the flame. Bonneted lamps were stated to have been used chiefly in strong currents‡—for example, in repairing work in shafts and airways, to avoid the risk of the flame being blown out, those mentioned being the Friemann and Wolf of Marsaut type; the Friemann and Wolf with air-feed below the flame and bonnet with slits; and the lamp of Bergwerksdirektor Meyer of Herne.

These remarks may, of course, apply only to one district in Germany, and to the particular time at which they were written.

* *Annales des Mines*, 1912, series 11, vol. i., *part. adm.*, page 264.

† *Die Entwickelung des Niederrheinisch-Westfälischen Steinkohlen-Bergbaues in der zweiten Hälfte des 19ten Jahrhunderts*, 1904, vol. vii., page 236.

‡ *Ibid.*, page 246. The reason for this was stated to have been that while the bonnet (Schutzmantel) lessened the danger from "blowing through," it increased the danger from internal explosion, because it interfered with the conduction of heat by the gauze.

Writing in 1899, Bergassessor Balzer, however, stated that the lamps used in Lower Silesia were of the Clanny type, with air-feed from above the flame.* The Police Regulations for the district of Breslau,† issued on January 18th, 1900, gave the same impression, since the type of safety-lamp prescribed for use was to be fitted with one gauze cap, the size of wire and mesh of the gauze being specified; air-feed either above or below the flame was permitted, but in the latter case the inlet-holes were to be protected. The lamp was to be fitted with an internal igniter of approved type. No lamp which did not comply with the regulations could be used, unless authorized by the Inspector General of Mines.

The lamps tested at Zwickau‡ at the request of the Royal Mining Office in Saxony in 1908-1909 appear also to have been of the Boty type, some with one gauze cap, and some with two. No mention appears to have been made of bonneted lamps.

The following references to tests conducted in various parts of Germany may be of interest. Most of them were undertaken in order to ascertain the safety of various types of re-lighter when used with benzine lamps.

In 1886 Dr. Broockmann§ made some experiments at Bochum on internal re-lighters in order to verify the results obtained by Dr. Schondorff when experimenting for the Sub-commission on Safety-lamps of the Prussian Firedamp Commission.¶

In 1896 Dr. Schondorff** carried out some tests on re-lighters at Saarbrücken. In the same year similar tests were made in an apparatus erected at the Glückhilf-Friedenshoffnung Mine at Waldenburg, Silesia.‖ Experiments on benzine lamps fitted with

* *Zeitschrift für das Berg-Hütten-und Salinenwesen im preussischen Staate*, 1900, vol. xlvii., B, page 323.

† *Ibid.*, vol. xlviii., A, page 66; translated in the *Annales des Mines de Belgique*, 1902, vol. vii., page 121.

‡ Die Lampenuntersuchungslutte der Firma Friemann und Wolf in Zwickau," by Berginspektor Bachmann, *Jahrbuch für das Berg-und Hüttenwesen im Königreiche Sachsen*, 1909, A, page 166.

§ The writers are indebted for this reference to "Experiments on Wolf Safety Lamps," issued in 1910 by the Wolf Safety Lamp Company, Limited.

‖ *Zeitschrift für das Berg-Hütten-und Salinenwesen im preussischen Staate*, 1886, vol. xxxiv., B, page 320.

¶ *Ibid.*, 1897, vol. xlv., B, page 226.

** The writers are indebted for this reference to "Expériences sur les Lampes de Sûreté," by MM. V. Watteyne and S. Stassart, *Annales des Mines de Belgique*, 1904, vol. ix., pages 972-982.

re-lighters were carried out at Neunkirchen*† in a lamp-testing apparatus of a type similar to that designed by Dr. Schondorff for the Austrian Firedamp Commission.‡

In 1899 tests on benzine lamps fitted with re-lighters used in the district of Lower Silesia were made at the testing-station of the Glückhilf-Friedenshoffnung Mine by Bergassessor Balzer of Waldenburg.*†§ In the same year an apparatus of the trough type for testing lamps was installed by the Westfälische Bergwerkschaftskasse at Bismarck Colliery,*† near Gelsenkirchen. Experiments on re-lighters were carried out by Bergassessor Fähndrich.‖

A testing-station appears also to have been erected at Beuthen,* in Upper Silesia.

In 1913 a lamp-testing apparatus of trough type was erected at Derne, near Dortmund.¶

In 1908 the firm of Friemann & Wolf, at the request of the Royal Mining Department ("Bergamt") in Freiberg, erected a lamp-testing station at Zwickau, Saxony, where tests were commenced in October of that year.

The apparatus was of the covered-trough type, with arrangements for testing lamps in ascending and descending currents, either vertically or at an angle; the area afforded by the trough was rather larger than that of the apparatus at Gelsenkirchen. Lighting-gas was used, and tests were made chiefly on lamps burning benzine, with single and double gauzes, and of both over air-feed and under air-feed types; and on lamps burning acetylene.

Experiments were also made with various types of re-lighters.

The paper** in which the apparatus and experiments were described instituted a comparison between the results obtained and those arrived at by Bergassessor Fähndrich at Gelsenkirchen.††

* See note § on previous page. † See note ¶ on previous page.

‡ *Zeitschrift für das Berg-Hütten-und Salinenwesen im preussischen Staate*, 1900, vol. xlv., B, page 249.

§ *Ibid.*, 1899, vol. xlvii., B, page 323.

‖ *Glückauf*, 1900, No. 38; 1901, No. 24.

¶ "Die Versuchsstreckenanlage in Derne," by Bergassessor Beyling and Bergassessor Zix, Dortmund, *Glückauf*, March 22nd, 1913; and *Annales des Mines de Belgique*, 1913, vol. xviii., page 873.

** "Die Lampenuntersuchungslutte der Firma Friemann & Wolf in Zwickau," by Berginspektor Bachmann, *Jahrbuch für das Berg-und Hüttenwesen im Königreiche Sachsen*, 1909, A, page 166.

†† Reference was made to *Glückauf*, 1901, No. 24.

The tests appeared to show that, so far as the behaviour of safety-lamps was concerned, it mattered little whether lighting-gas or firedamp was used to form the explosive mixture; but that when lighting-gas was used the conditions were a little more stringent, owing to the fact that lighting-gas was more easily inflammable than firedamp.

The writers have brought their paper to a close at the end of the year 1913, because, for reasons already stated, they regard the history of the safety-lamp as commencing in 1813, although the Davy lamp was not invented until towards the close of the year 1815. Another reason which decided them to adopt this course has been the difficulty of writing with accuracy about contemporary events, and the fact that since the outbreak of the great European War in August, 1914, the course of events has not been normal, and possibly the development of the safety-lamp has in consequence been arrested.

A list of some publications relating to the history of the safety-lamp and to the early history of firedamp is given in Appendix II.

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## APPENDIX I.

LIST OF SAFETY-LAMPS DESCRIBED IN APPENDIX XXIV. TO THE FINAL REPORT OF THE ROYAL COMMISSION ON ACCIDENTS IN MINES, 1886.*

### DAVY TYPE.

Eleven "Common" Davy lamps were submitted to the Commission: two Evan Thomas, Aberdare; one Cooke & Company, Birmingham; one Davis, Derby; one Naylor, Wigan; and six not stated.

Eight Davy lamps with a shield; one Evan Thomas; one Watson, Newcastle-upon-Tyne; one Jenkins, Ocean Colliery; and five not stated.

Douglas & Mason.

Scotch, Nos. 1 and 2.

Jack lamp, or Davy with glass shield*:—Ten examples were submitted to the Commission: one Protector Lamp Company; one John Knowles, Wigan; and eight not stated.

In addition there were:—Ashworth, No. 2, a Jack lamp fitted with a gauze diaphragm holding a cylindrical gauze chimney, and constructed to burn petroleum spirit.

Perkins.

Porter.

Reay.

Davy in case*:—Eight examples were submitted to the commission: two Abbot & Company,* Gateshead-upon-Tyne; three Wood,* South Hetton

* Those lamps of which illustrations are given in Appendix xxiv. are marked with an asterisk.

Colliery; one Benjamin Glover, Haydock Colliery; one Wharton*; and one not stated.

In addition there were:—Ayton, No. 1; the case was stated to resemble a Gray lamp.

Ayton, Nos. 2, 3, 4, and 5*; case was practically that of an Eloin lamp, but there was an additional gauze cap interposed between the Davy gauze cylinder, and the Eloin tube above the glass.

J. M. Foster.

Hyde, a fixed lamp intended to give an alarm if firedamp was present.

Routledge & Johnson, Nos. 1, 2, 3, and 4*; "a Davy lamp enclosed in a Clanny lamp with external shield."

Wearmouth.*

Pieler, for indication of firedamp.

### STEPHENSON TYPE.

Eight Stephenson lamps were tested by the Commission: three from Killingworth Colliery; two Davis, Derby; two Protector; and one C. H. Cobbold, Elsecar.

In addition there were:—Hann, Nos. 1, 2, 5, and 6.*

Williamson, Nos. 1, 2, 3, 5, 6, 7, and 8,* described as being "of the Stephenson type." The Stephenson lamp was placed in a case which had the form of a Clanny lamp, but air was admitted below the glass.

### CLANNY TYPE.

#### (*a*) *Unbonneted Lamps.*

Sixteen "Common" Clanny lamps were examined by the Commission: seven Evan Thomas, Aberdare; two Jenkins, Ocean Colliery; one Mills & Son, Newcastle-upon-Tyne; one Moore, Treherbert; one Naylor, Wigan; two Protector Lamp Company; and two Watson, Newcastle-upon-Tyne.

Leach, with a close spiral coil of iron wire inside the gauze, to act as an internal shield.

Pelton, Nos. 1,* 2, and 3, with two glasses, and metal tubes inside the gauze cap.

Rotherham.

Shakespear, Nos. 8 and 9.

Westphalian, No. 1, with gauze of 1,024 apertures to the square inch.

Wolf, from Zwickau; constructed to burn "benzoline," and fitted with an internal re-lighter. The gauze had 1,296 openings to the square inch.

#### (*b*) *Bonneted Lamps.*

Five bonneted Clanny lamps were submitted, namely, two Ashworth*; two Protector Lamp Company; and one not stated.

Ashworth, Nos. 4,* 5, and 6, Clanny lamps, with a double bonnet.

Evan Evans,* Llanrwst.

Evan Thomas, Nos. 5,* 6, and 7.*

Thomas Thomas.

### MUESELER TYPE.

#### (*a*) *Unbonneted Lamps.*

Nine Mueseler lamps from Belgium*; one Dinas Colliery; one Llwynypia Colliery; one Insole & Sons; one Cross Keys Colliery; three Celynen Colliery;

three Evan Thomas; one Mardy Colliery; one Hetton Colliery; three Davis & Son, Derby; one Borsay; five Protector Light Company; one Mills & Son, Newcastle-upon-Tyne; one Wilkinson, from Risca Colliery; Scarborough, Nos. 1, 2, and 3; two Somzee; two Cymmer Colliery; Bryham Nos. 1, 2,* and 3; and two Shireoaks Colliery.

Ashworth, No. 1, burning petroleum; Ashworth, No. 3.

Mackworth.

Shakespear, No. 10.

Strelley.

(*b*) *Shielded Lamps.*

Routledge & Johnson, Nos. 5* and 6, "resembling a Mueseler, but without the horizontal gauze diaphragm, enclosed in a Clanny case with a shield."

(*c*) *Bonneted Lamps.*

Two Johnson, Clapham, & Morris; three William Smethurst*; one A. H. Stokes, H.M. Inspector of Mines.

Garforth, with gas-detector.

Morgan.*

Thomson, Nos. 1 and 2.*

BOTY TYPE.

Bainbridge, Nos. 1,* 2, 3, 4, 5, and 6; and No. 7, with Mueseler gauze diaphragm and chimney above the glass.

Gissing, Nos. 1 and 2.

Schöne.

Westphalian, No. 2.

Wethered, with two gauze caps.

ELOIN TYPE.

Eloin.*

Fumat, Nos. 1 and 2.*

Gardner.

Hann, Nos. 3 and 4.

Horn.

Howat, Nos. 1, 2, 3*, 4, and 5*.

Pelton, No. 4.*

Purdy, Nos. 1 and 2.*

Smethurst, Nos. 1, 2, 3, 4, 5, 6, 7, and 8.

Soar,* with bonnet.

Timmis.

Upton and Roberts; "behaves very much like an Eloin lamp."

Williamson, No. 4; "practically an Eloin lamp."

Evan Thomas, Nos. 1, 2, 3,* and 4. The Commission reported of No. 1 that it was "a lamp of the Eloin type enclosed in a case." The lamp had double glasses, two shields, and a chimney; air was derived from the space between the two shields at the top of the lamp; and passed through the space between the two glasses and through two strips of gauze to the flame.

GRAY TYPE.

(Lamps of this type were referred by the Commission to the Eloin type)

Clifton,* for experimental purposes.

Gray, Nos. 1, 2,* and 3.

Smith.

### MARSAUT TYPE.

Nine Marsaut lamps were tested: two M. Marsaut; two Protector Lamp Company; one Armstrong, Chester-le-Street; one Davis & Son, Derby; one Mills & Son, Newcastle-upon-Tyne; and two not stated.*

### LAMPS NOT REFERRED TO ANY SPECIAL TYPE.

Ballardie.

Bradshaw.

Crossley, independent of the surrounding atmosphere, being supplied with air from a reservoir containing compressed air.

Haworth.

Heinzerling, inlet and outlet of air through cylindrical gauze boxes packed with glass-wool.

Humble.

Lucas, Nos. 1 and 2.

McKinless, a gauzeless lamp.

Morison, Nos. 1* and 2.

Pendleton.

Young, constructed to burn solid paraffin.

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## APPENDIX II.

### LIST OF SOME PUBLICATIONS RELATING TO THE SAFETY-LAMP AND TO THE EARLY HISTORY OF FIREDAMP.

### MISCELLANEOUS.

1708.—"The Compleat Collier; or the whole Art of Working Coal Mines in the Northern Parts," reprint (1845) by M. A. Richardson, Newcastle-upon-Tyne.

1742.—NORTH, THE HON. ROGER, "The Life of the Right Honourable Francis North."

1755.—DALTON, THE REV. JOHN, D.D., "A Descriptive Poem addressed to two Ladies at their Return from viewing the Mines near Whitehaven."

1763.—Académie Royale des Sciences, Paris, "Sur les Matières inflammables qui se trouvent dans les Mines de Charbon de Terre, et sur les Moyens de s'en garantir."

1794.—HUTCHINSON, WILLIAM, F.A.S., "The History of the County of Cumberland."

1799.—VON HUMBOLDT, BARON FRIEDRICH ALEXANDER, "Ueber die unterirdischen Gasarten und die Mittel ihren Nachtheil zu vermindern."

1801.—DIXON, J., M.D., "The Literary Life of William Brownrigg, D.D., F.R.S."

1805.—TROTTER, T., M.D., "A Proposal for destroying the Fire and Choak Damps of Coal Mines."

1806.—TROTTER, T., M.D., "A Second Address to the Owners and Agents of Coal Mines on Destroying the Fire and Choak Damp."

1814.—"First Report of a Society for Preventing Accidents in Coal Mines."

1815.—"On Safe Lamps for Coal Mines, with a Description of the one invented by Mr. Stephenson of Killingworth Colliery," by Alexander Tilloch, *The Philosophical Magazine and Journal*, 1815, vol. xlvi., page 458.

1816.—DAVY, SIR HUMPHRY, LL.D., "Practical Hints on the Application of Wire Gauze to Lamps for preventing Explosions in Coal Mines."

1816.—Clanny, W. R., M.D., "Practical Observations on Safety Lamps for Coal Mines."

1816.—Holmes, J. H. H., "A Treatise on the Coal Mines of Durham and Northumberland."

1816.—Children, J. G., "On Sir Humphry Davy's Safe-Lamp for Mines."

1816.—"On Lighting Coal Mines," *Annals of Philosophy*, by Dr. T. Thomson, 1816, vol. vii., page 117.

1816.—Clanny, Dr. W. R., "Practical Observations on Safety Lamps for Coal Mines," *Annals of Philosophy*, by Dr. T. Thomson, 1816, vol. viii., page 353.

1817.—Stephenson, George, "A description of the Safety Lamp invented by George Stephenson and now in use at Killingworth Colliery."

1817.—"A Collection of all the Letters which have appeared in the Newcastle Papers with other Documents relating to the Safety Lamp."

1817.—"Report upon the Claims of Mr. George Stephenson Relative to the Invention of his Safety Lamp."

1818.—Davy, Sir Humphry, "On the Safety Lamp for Coal Miners, with some Researches on Flame."

1818.—"Safety Lamp Controversy," *The Philosophical Magazine and Journal*, by Alexander Tilloch, 1818, vol. li., page 63.

1823.—"Report from the Select Committee on Gas-light Establishments," July 7th, 1823.

1823.—Chèvremont, M., "Sur plusieurs Perfectionnements faits à la Lampe de Sûreté de Sir Humphry Davy," *Annales des Mines*, 1823, series 1, vol. viii., page 209.

1825.—"Instruction pratique sur l'Emploi des Lampes de Sûreté dans les Mines," etc., *Annales des Mines*, 1825, series 1, vol. x., page 3.

1825.—Mackenzie, E., "An Historical, Topographical, and Descriptive View of the County of Northumberland," vol. i., pages 91-94.

1830.—Davy, Dr. J., "The Collected Works of Sir Humphry Davy"; vol. i., "Memoir of the Life of Sir Humphry Davy"; vol. vi., "Papers on the Safety Lamp and Flame" (1840).

1831.—Paris, J. A., M.D., "The Life of Sir Humphry Davy."

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1833.—"The Insecurity of Sir H. Davy's Lamp demonstrated by a Series of Chemical Experiments, and the Perfect Security of Upton & Roberts's New Safety Lamp" (pamphlet).

1835.—"Report from the Select Committee on Accidents in Mines."

1839.—Gruner, M., "Rapport sur les Expériences faites à Saint Étienne au Moyen de la Lampe de M. du Mesnil," *Annales des Mines*, 1839, series 3, vol. xvi., page 511.

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1847.—BLAVIER, M., "Rapport sur la Lampe de Sûreté du Sieur Dubrulle," *Annales des Mines*, 1847, series 4, vol. xi., page 105.
1847.—"Reports on the Gases and Explosions in Collieries," Sir Henry de la Beche, Dr. Lyon Playfair, and Mr. Warington Smyth.
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1852.—"Report from the Select Committee on Coal Mines," 1852.
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1853.—PONSON, A. T., "Traîté de l'Exploitation des Mines de Houille."
1853.—"Report from the Select Committee on Accidents in Coal Mines," 1853, first, second, and third reports.
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1854.—HALL, T. Y., "A Treatise on the Extent and Probable Duration of the Northern Coalfield," parts 6 and 7.
1854.—MACKWORTH, H., "Science in the Mines."
1857.—RAINE, REV. J., "Memoir of the Rev. John Hodgson, M.A."
1858.—SMILES, S., "Life of George Stephenson, Railway Engineer."
1861.—PROUTEAUX, A., "Des Lampes de Sûreté dans les Mines de Houille. Lampe de M. Laurent-Lermusiaux à Ouverture Pneumatique."
1861, 1865.—BURAT, A., "Matériel des Houillières en France et en Belgique."
1863.—MALHERBE, R., "De l'Exploitation de la Houille dans le Pays de Liége."
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1902-03.—Ashworth, J., "The Gray Type of Safety-lamp," vol. xxv., page 62.
1902-03.—Best, W., "A Magnetic Unlocking and Electrically-ignited Safety-lamp," vol. xxv., page 265.
1903-04.—Watteyne, V., "The Purpose and Present State of the First Experiments on Safety-lamps and Explosives Carried out at the Frameries Experimental Station, Belgium," vol. xxvii., page 445.
1904-05.—Lishman, G. P., "Notes on Safety-lamp Oils," vol. xxviii., page 338.
1905-06.—Ashworth, J., "The Elba and Clydach Vale Colliery Explosions," vol. xxx., page 509.
1905-06.—Latham, C., "Notes on the Detection and Estimation of Inflammable Gases in Mines by Means of Flame-caps," vol. xxxi., page 136.
1906-07.—Wilson, J. R. R., "Presidential Address," vol. xxxii., page 256.
1906-07.—Hodgson, L. H., "The Wolf Safety-lamp," vol. xxxii., page 300.
1906-07.—Hodgson, L. H., "Acetylene Safety-lamps," vol. xxxii., page 305.
1909-10.—Winstanley, G. H., "An Apparatus to Facilitate the Prolonged and Careful Study of Gas-caps Produced on the Flame of an Ordinary Safety-lamp by Accurately-determined Percentages of Firedamp," vol. xxxviii., page 235.
1909-10.—Cadman, J., "Lamp to Detect Small Percentages of Firedamp," vol. xxxviii., page 259.
1909-10.—Whalley, E. B., and Tweedie, W. M., "Firedamp Caps and the Detection of Firedamp in Mines by Means of Safety-lamps," vol. xxxviii., page 509.
1909-10.—Hailwood, E. A., "The Cunynghame-Cadman Gas-detecting Device," vol. xxxix., page 13.
1909-10.—Gray, T., "Firedamp: its Composition, Detection, and Estimation," vol. xxxix., page 286.
1909-10.—Stopford, T. R., "Some Recent Improvements in Miners' Safety-lamps," vol. xxxix., page 800.
1910-11.—Cochrane, R. D., "A New Method of Testing for Gas in Mines with Safety-lamps," vol. xl., page 272.
1910-11.—Winstanley, G. H., "The Safety-lamp as an Instrument for the Detection and Estimation of Firedamp in Mines," vol. xl., page 338.
1911-12.—Briggs, H., "Testing for Firedamp and Black-damp by Means of a Safety-lamp," vol. xliii., page 64.
1912-13.—Hailwood, E. A., "The Hailwood Gas-cap Observation-machine," vol. xliv., page 503.
1912-13.—Wilson, C. J., "An Investigation into the Effect of Atmospheric Pressure on the Height of the Gas-cap," vol. xlv., page 67.
1912-13.—Saint, T. A., "The Lighting Efficiency of Safety-lamps," vol. xlv., page 327.
1913-14.—Briggs, H., "Gas-caps and Fuel-caps," vol. xlvi., page 204.
1913-14.—Lodge, G. A., "The Effect of Increased Atmospheric Pressure on the Height of the Gas-cap," vol. xlvi., page 311.
1914-15.—Hailwood, E. A., "Miners' Electric Lamps Compared with the Combustion-tube Oil-lamp," vol. xlviii., page 192.

1914-15.—MAURICE, W.—"The Case for the Electric Lamp," vol. xlviii., page 286.
1914-15.—BRIGGS, H., "A Method for the Rapid Estimation of Oxygen and Blackdamp in the Air of Safety-lamp Mines," vol. li., page 169.

PROCEEDINGS OF THE SOUTH WALES INSTITUTE OF ENGINEERS.

1859-61.—WARING, C. H., "On an Improved Miners' Safety-lamp," vol. ii., page 161.
1876-77.—TEALE, W. E., "On Safety-lamps," vol. x., page 239.
1876-77.—GALLOWAY, W., "On the Firedamp Cap," vol. x., page 284.
1880-81.—CROSSLEY, W., "Description of 'Crossley's Patent Compressed-air Safety-lamp,'" vol. xii., page 411.
1884-85.—STEER, A., "Miners' Safety-lamps Compared with the Morgan Lamp," vol. xiv., page 104.
1884-85.—CLAPP, W. J., "Clapp and Sandbrook's Improved Safety-lamp," vol. xiv., page 377.
1886-87.—HANN, E. M., "Lighting Safety-lamps when Locked," vol. xv., page 74.
1886-87.—MERCIER, M., "Mercier's Improved Safety-lamps," vol. xv., page 118.
1890-91.—THORNE, J., "Miners' lamps," vol. xvii., page 117.
1892-93.—REES, J. P.—"Safety Lock for Existing Miners' Lamps," vol. xviii., page 169.
1892-93.—TEALE, W. E., "The Miners' Piston Safety-lamp," vol. xviii., page 172.
1892-93.—CLOWES, F., "The Hydrogen-oil Safety-lamp," vol. xviii., page 293.
1892-93.—CLOWES, F., "Test-chamber for Showing and Measuring the Indications given by Gas-testing Apparatus," vol. xviii., page 299.
1892-93.—DAVISON, J. W., "New Lock for Safety-lamps," vol. xviii., page 407.
1894-95.—BEST, W., "The Best Miners' Safety-lamp, and Electric Lighting Apparatus," vol. xix., page 256.
1894-95.—DAVIES, W., "Extinguishing Attachment for Miners' Safety-lamps," vol. xix., page 394.
1902-03.—PATTERSON, W., "Patterson's Patent Safety-lamp, with Baxendale's System of Handling it in the Lamp Room and Method of Relighting in the Pit," vol. xxiii., page 157.
1906-07.—BEST, W., "Some Recent Improvements in Connection with Miners' Safety-lamps and the Electrically Igniting of Same Underground," vol. xxv., page 156.

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Lieut.-Colonel W. C. BLACKETT (Sacriston) said that an interesting point to note was the manner in which the use of the safety-lamp had entirely changed. The labours of Sir Humphry Davy, Stephenson, and others were directed towards the invention of a safety-lamp for the purpose of working mines in the presence of a dangerous quantity of gas; but the safety-lamp was no longer devoted to that purpose: it was used to give warning when gas was present, in order that the miners should not continue to work in gas.

He would remind the members that the Nicholas Wood who took so prominent a part with Stephenson in carrying on experiments with safety-lamps still had a son in the North of England in Sir Lindsay Wood, Bart., the head and chief of the coal-industry of Durham.

Mr. JAMES ASHWORTH (Vancouver, B.C.) wrote that a translation of the Belgian Report,* attributed in error to Mr. C. G. Jackson, of Wigan, was published as a preface to the writer's paper on the Davy and Mueseler types of safety-lamps read before the North of England Institute of Mining and Mechanical Engineers.†

The writer commenced in 1878 to make experiments on safety-lamps. These led him to recognize that the Mueseler type of lamp possessed the most essential qualifications for a reliable safety-lamp, and he proceeded to adapt these good points to the Davy and Stephenson lamps. These suggested alterations in construction are shown in the writer's paper, one of which was the addition of a gauze chimney and gauze disc placed inside the single Davy gauze slightly below the top of the glass shield. This lamp stood the very severe tests made by Mr. W. Smethurst and the writer at Garswood Hall, and later by the Royal Commission on Accidents in Mines. Experiments made in collaboration with Mr. W. Smethurst at Garswood Hall disclosed the fact that the most dangerous feature of the Stephenson lamp (when exposed to an explosive atmosphere) was due to the fact that the space allowed for the entry of air below the internal glass cylinder was too small to supply the wick-flame and ventilate the lamp, and, therefore, another supply of air entered on the windward side of the lamp through the perforated copper cap and circulated down the inside of the glass. Thus, when this lamp was raised into firedamp, the top part of the lamp became charged with a highly explosive mixture, which, as soon as it came into contact with the wick-flame, exploded with such violence that the resulting flame passed right through both the copper cap and the covering gauze. This was just the "cannon effect" referred to by M. Marsaut as being the dangerous feature of the Clanny type of safety-lamp. Mr. John Gerrard, H.M.

* *Trans. N. E. Inst.*, 1879-1880, vol. xxix., page 113.

† *Ibid.*, page 145.

Inspector of Mines, attributed the cause of the Swaithe Main explosion to the failure of a Stephenson lamp, and, a few years later, this opinion was confirmed by the failure of a Stephenson lamp at the West Ardsley Colliery.

The writer came to the conclusion that the weak point of the Mueseler type of lamp was due to the reversal of the air-current, and, in order to prevent this, he (Mr. Ashworth) placed a cowl over the chimney top, and a special shield over the disc-gauze. One practical result of the Garswood Hall (Bryan) experiments was that Messrs. Cross, Tetley, & Company altered their Davy lamps by substituting a long glass shield in place of the tin shield. This glass shield only differed from that of the Jack Davy lamp in that it was longer and overlapped the top or smoke gauze of the lamp by half an inch, and thus in effect made it a double-gauze lamp. The Royal Commission of 1886 commenced its experiments with the same apparatus as that used by Mr. Smethurst and the writer.

The Garswood Hall experiments were to have been continued with the addition of coal-dust, but this part of the investigation was transferred to Harecastle, North Staffordshire, where a committee of the North Staffordshire Institute of Mining and Mechanical Engineers had erected a testing gallery similar to the one at Garswood Hall. The experiments with gas only, however, had to be adjourned, owing to deficiency of gas-supply (lighting-gas), but some experiments were made with tin-shielded Davy lamps (unbonneted) in a current of air travelling at 6 feet per second and laden with 4½ per cent. of gas and a normal content of coal-dust from the Banbury Eight-Foot Seam. The lamps passed the flame in 10 seconds and exploded the current. The writer was not aware that there was any record of similar experiments having been made in Great Britain, nor had this phase of the subject received the serious attention which it deserved, especially by experimenters who have tested safety-lamps after explosions, where suspicion pointed directly to a safety-lamp failure as the originating cause.

With regard to the Gray lamp, it appeared to him that it had the following advantages: (1) it had the qualifications of a Mueseler; (2) the whole of the air entering the lamp must pass over the flame; (3) the quantity and velocity of the air-feed were absolutely regulated by the diameter of the conical opening

at the top of the chimney, by the area of the gauze below the wick-flame, and by the diameter of the inlet-air tubes; (4) it could not be exploded without reversing the ventilation, and this was only possible when the conical outlet of the chimney was cut away and the shield removed. One lamp only, which was purposely thus damaged, had been known to pass the flame, and that was at Rotherham, in the apparatus used by Mr. C. E. Rhodes and the Midland Institute. With regard to the adoption of the bonnet or shield, the writer would point out that he supplied to the Royal Commission many lamps to be tested. Among these were two: the first of the present-day type of bonneted safety-lamps which were tested by the Commissioners. These lamps preceded the patenting in Great Britain of the Marsaut shield, and were recorded in the official report as Clanny Nos. 17 and 18. These two lamps in particular were very important in the English history of safety-lamps, as their priority over the Marsaut saved the mining interests a very large sum of money in royalties. Later still the Ashworth-Clanny No. 4 was sent in; it was fitted with two complete shields, the inner one having a conical outlet. This lamp gave remarkable results as a single-gauze lamp.

In 1887 the writer patented his first improved Gray safety-lamp, known as the Ashworth-Hepplewhite-Gray, later as the A.H.G., and sometimes as the Hepplewhite-Gray.

During later years various alterations were made in the outward appearance of the Gray lamp: thus the four air-tubes were reduced to three, and later to one only, and the lamps were also adapted to burn petroleum, mineral colza, benzoline, colzaline, alcohol, wood-spirit, and, lastly, hydrogen gas Ashworth-Clowes lamp). For high illumination the Gray type is ideal, the latest pattern produced by the writer giving 1·25 per cent. of a standard sperm-candle light. The Ashworth alcohol gas-tester gives a 3-inch cap with 1 per cent. of firedamp. In order to obtain a good test for low percentages of firedamp, a hot non-luminous flame is required, and for this purpose a single-wick of peculiar shape was adopted, also duplex flat and triplex round wicks.

In the early part of these notes the writer referred to the use of a gauze chimney in place of the Mueseler metal chimney, and this form of chimney was later on adopted, with the addition

of a small length of metal tube to form the base to which the gauze chimney and the conical gauze-disc were attached—the latter giving a larger area of inlet-air room than does the usual or horizontal form. The Ashworth-Mueseler lamp also has an internal shield with a conical outlet, as in the Ashworth No. 4 Clanny, and outside that again the ordinary bonnet or shield. Over the inlet-air holes at the base of the shield a movable shutter was affixed, so that when it was closed the atmosphere to be tested was compelled to enter from nearly the top of the shield, and to pass down between the two shields, through the holes in the base of the inner shield to the lamp-flame. This form of lamp has never failed, nor has it been exploded, either in this country or on the Continent, when exposed to the highest explosive air-currents. The Ashworth-Gray type of safety-lamp as now constructed has several notable features; thus, the inlet openings are completely protected from all directions and velocities of air-current; coal-dust cannot get to the gauze above the wick-flame, the gauze cannot become red-hot (except owing to carelessness when manipulating the hydrogen flame), and the lower gauze cannot possibly become red hot, because the flame from any burning gas is compelled to pass up and away from the gauze. Finger-holes are provided in the inlet-tube or tubes, so that when a gas-tester or fireman has made a test, he can prevent his wick-flame from being extinguished by excess of gas by admitting air at a gas-free level.

Any history of the improvements to safety-lamps would be incomplete without a reference to the glass part. Thus the writer, to increase the lighting power of miners' safety-lamps, and to protect miners' eyes, made and patented a glass with a white enamel streak down a third of the vertical side, which, whilst increasing the illumination, also protected the miners' eyes from glass glare, without shutting out the light entirely. Thus also, by frosting or colouring the *inside* of the lamp-glasses a dull black, the glass glare was again nullified, and it formed the best background for viewing gas-caps when estimating quantities of firedamp.

The writer would draw attention to the fact that coal-mine gases have at odd times been collected and analysed, and found to contain hydrocarbon gases other than methane. In 1904 the writer came to the conclusion that ethane was present in some of

the Crows' Nest Pass mines, and Prof. P. Philips Bedson found this, and other gases, and extracted them from a sealed sample of coal-dust submitted to him. In 1910 Prof. John Cadman also found ethane in the air of the Bellevue Mine of Alberta. In the mines of Great Britain the writer does not remember seeing an analysis of " firedamp " from any district which gave ethane as a constituent, but there have been several well-known failures of safety-lamps which could not be repeated under experiment, and in no case was the mine-gas analysed. He can recall failures at West Ardsley, Speakmans, West Leigh, the second Albion, Charlesworth, and lastly the failure of a bonneted Clanny lamp whilst a fireman was making a test for gas in the Pentre Pit, Rhondda Valley. The highest percentage of ethane that the writer remembers to have seen recorded was found in German coal-mines.

The AUTHORS wrote that they were much interested in Mr. Ashworth's remarks; they noticed that in them the name of the place where Mr. Smethurst and Mr. Ashworth conducted their tests on safety-lamps was given as Garswood Hall, whereas in the paper read before the Manchester Geological Society* it was called Brynn. They concluded, however, that the two names referred to the same place. Whilst the authors had referred to the early history of firedamp and its occurrence, they had not entered into a discussion on its composition, as they considered that was hardly germane to the subject; but as Mr. Ashworth had raised the question they might say that the expression " firedamp " was useful because it referred to a mixture of gases, the composition of which defied accurate definition. Firedamp varied not only in the amount of methane ($CH_4$) present, but also as to the presence of other hydrocarbon gases alluded to by Mr. Ashworth. The natural gas at Garswood Hall used by the British Royal Commission of 1886 contained from 84·16 to 88·86 per cent. of marsh-gas†, the other gases being carbonic-acid gas, oxygen, and nitrogen; while the gas (" grisou ") at Frameries‡ appears to have contained about 80 per cent. of methane ($CH_4$) and 2·5 of carbon dioxide ($CO_2$).

* *Transactions of the Manchester Geological Society*, 1878-1879, vol. xv., page 115.

† *Final Report of the Royal Commission on Accidents in Mines*, 1886, Appendix v., page 144.

‡ " Le Siège d'Expériences de l'Administration des Mines à Frameries," by V. Watteyne, *Annales des Mines de Belgique*, 1904, vol. ix., page 171.

The French Firedamp Commission in their Report* of 1882 found that firedamp was almost entirely composed of marsh-gas with the elements of air more or less deficient in oxygen, and only a few hundredths of hydrogen, or of complex hydrocarbons on the one hand, and of carbon dioxide on the other hand.

The Prussian Firedamp Commission† devoted attention to the other hydrocarbon gases contained in firedamp, and in their report they published several analyses of the gas found in Germany. From this they concluded that, in addition to fire-damp, several of the higher hydrocarbon gases occurred‡; "these are, according to the most recent investigations, chiefly ethane ($C_2H_6$), occasionally propane ($C_3H_8$), butylene ($C_4H_8$), and butane ($C_4H_{10}$). As to other combustible gases, hydrogen is pretty generally found, but the presence of carbon monoxide and of sulphuretted hydrogen in fire-damp appears to be exceptional. Carbon dioxide is seldom absent, and, in addition, nitrogen and oxygen are frequently met with." Sample xix. of the Commission, from a blower at the Schaumburg Collieries at Obernkirchen, showed 60·46 per cent. methane, and 37·62 ethane, and was probably the one to which Mr. Ashworth referred. The subject was also dealt with in a paper by Dr. Thomas Gray contributed to the *Transactions* of the Institution in 1910.§

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* Page 19.

† *Trans. Inst. M.E.*, 1891-1892, vol. iii., page 1105.

‡ *Ibid.*, page 1133.

§ *Ibid.*, 1909-1910, vol. xxxix., page 286.

# INDEX TO VOL. LI.

EXPLANATIONS.

The —, at the beginning of a line denotes the repetition of a word or words followed by a comma in the preceding entry; and in the case of Names, it includes both the Christian Name and the Surname; or, in the case of the name of any Firm, Association, or Institution, the full name of such Firm, etc.

Discussions are printed in *italics*.

The following contractions are used:—

M. C.—The Midland Counties Institution of Engineers.
M. G.—The Manchester Geological and Mining Society.
M. I.—The Midland Institute of Mining, Civil, and Mechanical Engineers.
N. E.—The North of England Institute of Mining and Mechanical Engineers.
N. S.—The North Staffordshire Institute of Mining and Mechanical Engineers.
S. I.—The Mining Institute of Scotland.
S. S.—The South Staffordshire and Warwickshire Institute of Mining Engineers.

A.

Abberley Hills, geology, 126.
ABBOTT, LEWIS, quoted, 145.
Absorption of oxygen by coal, 493, 510. —Discussion, 532.
Accidents in coal-mines, death-rates, 470.
—, decrease at coal-face, reasons, 465.
Accounts, S. I., 290.
ADDISON, —, quoted, 615.
Address, chairman's, 462.
ADVISORY COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH, list of members, 463.
AGUILLON, —, quoted, 692.
AILLOT, —, quoted, 632.
Air-compressors for mining work, after-coolers, 7, 25, 27.
—, air-mains, 21.
—, air-pressures suitable, 25, 33.
—, air-surging in pipes, 16.
—, automatic air-valves, 4.
—, efficiency, 9.
—, —, volumetric, 10.
—, electrically driven, 6.
—, —, efficiency, 11.
—, —, governing of, 12.
—, —, lay-out of, 20.
—, exhaust-steam-driven, reciprocating type, 6.
—, —, tandem arrangement suggested, 29.
—, explosions in, cause, 31, 164.
Air-compressors for mining work, filtering arrangements, 17.
—, gearing, objections to, 5.
—, governing of, 11.
—, high-speed, 2.
—, —, objections to, 27.
—, horse-power of units, 3.
—, inbye, electrically driven, 33.
—, indicator diagrams, 13, 14, 16.
—, intercoolers, design of, 6.
—, knocking of, cause, 17.
—, leakage-tests, 14.
—, low-speed, conversion to high-speed, 24.
—, lubrication, oil-consumption, 20, 23, 32.
—, pipework, 15.
—, piston-rods, advantages, 3.
—, reciprocating types, efficiency of, size of units and, 30.
—, steam-driven, 6.
—, —, efficiency diagram, 10.
—, —, governor for, 11.
—, trunk-types, design of, 4.
—, —, objections to, 3, 27, 28.
—, turbo-compressors, considerations regarding, 8, 9.
—, vertical types, advantages, 5.
Air-meters, compressed air, surging of air and, 160.
Ammonia, uses of, 466.

Analyses, blackdamp, St. Germains colliery, 173.
—, coal, anthracite, 517.
—, —, Ayrshire, 528.
—, —, barnsley seam, 515, 516.
—, —, bullhurst seam, 525.
—, —, Durham, 520.
—, —, lignite, Portrush, 527.
—, —, Northumberland, 520.
—, —, Staffordshire thick, 526.
—, —, Welsh steam, 519.
—, gases from underground fire, Senghenydd colliery, 237.
—, steel and iron for colliery use, 250, 253.
Analysis, coal, 511.
—, —, estimation of moisture, 484.
—, gases at underground fire, 216.
ANDERSON, JAMES, quoted, 621.
Annual report of council, S.I., 288.
ANSELL, —, quoted, 615.
ANSTED, D. T., quoted, 619.
Anthracite coal, absorption of oxygen by, 517.
—, analyses, 517.
ARBER, E. A. NEWELL, quoted, 100, 112, 114, 118, 119, 120, 125, 138, 135, 145.
ARMCO iron, composition and properties, 250.
ARNOLD, J., quoted, 250.
ARNOULD, M. G., quoted, 620, 630, 631, 632, 633, 645, 646, 651.
ASHWORTH, JAMES, *absorption of oxygen by coal*, 545.
—, *history of safety-lamp*, 719.
—, *logic of trams*, 361.
—, quoted, 608, 685.
ASHWORTH-GRAY safety-lamps, development of, 719.
—, firedamp detecting, 685.
ASHWORTH-HEPPLEWHITE-GRAY safety-lamp, 677, 678.
Askern Main colliery, depth of barnsley seam at, 431.
ATHERTON, H. STANLEY, *south Lancashire coalfield, etc.*, 98.
ATKINSON, JOHN, quoted, 620.
ATKINSON, W. N., Institution medal awarded to, 462.
—, quoted, 185, 221, 531.
Atmospheric oxidation of iron pyrites, 500.—Discussion, 532.
Auditors, viii.
Axles for pit-tubs, specification of material for, 252.
AYRE safety-lamp, 604.
Ayrshire, coals from, absorption of oxygen by, 528.
—, underground fires at collieries in, 529, 537.

B.

BACHHOFFNER, —, quoted, 613, 623, 626.
BACHMANN, —, quoted, 697.
BAGOT, ALAN C., quoted, 648.
BAILEY, T. H., *health of old colliers*, 479.
BAILLOT, —, quoted, 594.
BAINBRIDGE safety-lamp, 640.
BALZER, —, quoted, 697, 698.
Banking arrangements at pit-bottom, Dykehead colliery, 337.
BANKS, SIR JOSEPH, quoted 592.
BARBER, CHRISTOPHER, election, M.I., 408.
BARKER, J. ELLIS, quoted, 54.
BARKLEY, J. T., quoted, 619.
Barnsley seam, coal from, absorption of oxygen by, 514, 516.
—, —, analyses, 515, 516.
—, depth at Askern Main colliery, 431.
—, Frickley trough, 430.
—, geometry of surface, 421.
—, pre-Permian contours of, 433.
—, —, exterpolation, 434.
BARNS'S safety-lamp, 679.
Barometric pressures, fluctuations of, underground fires and, 228.
—, water-gauge readings at underground fires and, 233.
BARRETTA safety-lamp, 672.
BARRINGTON, SHUTE, quoted, 559.
BARROIS, C., quoted, 116, 149.
BARROW, G., quoted, 148.
BARROWMAN, JAMES, quoted, 549, 620.
BARTHOLOMEW & COMPANY, JOHN, quoted, 413.
Batteries, Hirsch electrical lamp, 61, 350, 388.
BATYFIELD, HENRY, election, N.E., 35.
BEACH, THOMAS, *pit-timber and its preservation*, 200, 203.
BEARD-MACKIE firedamp indicator, 686.
BEATTIE, J. M., quoted, 475.
BEAUMONT, —, quoted, 615.
BEAUMONT, J., quoted, 550, 615.
BECHE, HENRY DE LA, quoted, 117, 601, 619.
BEDDOES, —, quoted, 576.
BEDSON, P. PHILLIPS, quoted, 369, 377, 723.
BEDSON, P. PHILLIPS, and L. L. BELINFANTE, quoted, 664.
BEDSON, P. PHILLIPS, and HENRY WIDDAS, quoted, 369.
Beehive coke-ovens, national loss of bye-products through use of, 467.
Belgium, physiography during Carboniferous period, millstone-grit, 112.
—, —, pendleside, 110.
—, —, tournaisian, 112.
—, safety-lamps in, introduction of Davy lamps, 595.
—, —, regulations regarding, 1851, 622.
—, —, —, 1904, 690.

Belinfante, L. L., and P. Phillips Bedson, quoted, 664.
Bell, Sir Lowthian, quoted, 205.
Belliss & Morcom, Limited, quoted, 23.
Bentley colliery, conditions of working at, 341, 349.
Benzol, uses of, 466.
Bert, Paul, quoted, 654.
Berthollet, —, quoted, 557.
Bertrand, Marcel, quoted, 101, 146, 412.
Bessemer steel, manufacture of, 247.
Beyling, —, quoted, 696.
Binns, G. J., *forming shaft-pillar in thin seams*, 457.
Biram safety-lamp, 618.
Birckel safety-lamp, 671.
Birkbeck, George, quoted, 596.
Birkbeck, Jno., quoted, 563.
Bischof, Gustave, quoted, 554, 596, 602, 635.
Black, James, election, councillor, S. I., 291.
—, forming shaft-pillar in thin seams. —Discussion, 166, 292, 457.
Blackdamp, analysis of, 185.
—, —, St. Germains colliery, 173.
Blackdamp and oxygen, estimation in safety-lamp mines, 169, 302.
—, —, accuracy of method, 178.
—, —, calibration of apparatus, 175, 179.
—, —, composition of blackdamp and, 183.
—, —, firedamp and, 184.
—, —, graduation of apparatus, 174.
—, —, precautions necessary, 173.
—, —, temperature and, 175.
—, —, water vapour and, 175.
Blackett, —, quoted, 568.
Blackett, W. C., *health of old colliers*, 479, 480.
—, history of the safety-lamp, 718.
Blackett, W. C., and R. Clive, quoted, 381.
Blatchford, A. S., influence of incombustible substances on coal-dust explosions, 369.—Discussion, 377, 401.
Body-Firket safety-lamp, 681.
Boilers, mechanical stokers for, fuel economy and, 460.
—, Meldrum furnaces, non-success of, 459.
—, tests on, points for consideration, 460.
Boisse, A. A. M., quoted, 554, 555, 595.
Bolton, Herbert, *connexions between north-western European coalfields*, 267.
—, quoted, 99, 137, 138, 145, 149.
Bonney, —, quoted, 120.
Bord-and-pillar workings, machine-mining in, 340 *et seq.*
Boreholes, determination of strike from, 417.
—, mapping of information from, 413.
Borlase, John B., quoted, 576.
Boty safety-lamp, 615.
Boty type safety-lamps, 701.
Boyes, Lieut. H. W., Military Cross awarded to, 289.
Boyle, Robert, quoted, 550.
Bragge, G. S., *forming shaft-pillar in thin seams*, 457.
—, *fuel economy*, 459, 460.
—, *modern American coal-mining methods*, 458.
—, *water-dams in coal at Netherseal colliery*, 456.
Bramall, E., *fuel economy*, 459, 461.
Bramall, Vincent, *economies in coal-washing*, 281.
Brande, W. T., quoted, 592.
Brandling, Charles John, quoted, 574, 591.
Brandling, R. W., quoted, 574, 590.
Brandling safety-lamp, 593.
Breton, L., quoted, 141.
Bricking scaffold, shaft-sinking, Dykehead colliery, 312.
Briggs, Henry, method for rapid estimation of oxygen and blackdamp in air of safety-lamp mines, 169.—Discussion, 187, 302.
Briggs loop for firedamp detection, 686.
Bristol coalfield, geology, 140.
British Columbia, coalfields, valuation of, 244.
British standard tests for wrought-iron, 258.
Bronchitis, liability of old coal-miners to, 473.
—, —, ventilation and, 474.
Brooke, W. J., quoted, 257.
Brown, E. O. Forster, *American coal-mining methods*, 54.
Brown, Myles, *logic of trams*, 367.
Brown & Company, Limited, John, quoted, 662.
Brownrigg, William, quoted, 552, 556, 557.
Buddle, John, quoted, 551, 552, 553, 554, 555, 560, 578, 583, 584, 587, 590, 593, 596, 597.
Buffer-ropes, winding, Dykehead colliery, 328.
Bulbs, Hirsch electrical lamp, 63.
Bullhurst seam, absorption of oxygen by coal from, 525.
—, pyrites in coal from, 522.
Bulman, H. F., *logic of trams*, 365.
Bunter period, denudation of European coalfields during, 123.
Burat, Amadée, quoted, 614.
Burn, W., quoted, 577.
Burr, Malcolm, quoted, 99.
Burt, Lieut. Andrew, death in action of, 289.

Buschmann safety-lamp, 672.
Butterfield, —, quoted, 145.
Bye-products, coal industry, increasing importance, 95.
Bye-products from coke-ovens, low temperature distillation and, 205.
—, national importance of, 466.
—, uses and markets, 204.

C.

Cadman, Lieut. Charles J., M.C., R.E., congratulations to, 1.
Cadman, Lieut. James, D.S.O., congratulations to, 1.
Cadman, John, C.M.G., congratulations to, 1.
—, quoted, 185, 531, 723.
—, *specification of iron and steel*, 261.
Cadman-Cunynghame firedamp detector, 686.
Cages, Dykehead colliery, 331.
—, —, buffer-blocks, 334.
—, —, detachable gates, 333.
—, —, fixed guides, 335.
—, —, guide-rope shoes, 333.
—, —, seat for, 324, 325, 326.
—, specification of material for, 253.
—, —, chains, 254.
Cail and Glover safety-lamp, 625.
Caledonian folds, European coalfields, 102.
Cambessédès safety-lamp, 679.
Cantrill, F., quoted, 125, 126, 127.
Cap-lamps, electrical, Hirsch, 64, 350.
Carbon dioxide, artificial generation of, 214.
—, chemical and physical properties of, 213.
—, coal-dust explosions and, 372.
—, recorder for use with flue-gases, 460.
Carbon dioxide and oxygen, estimation in safety-lamp mines, 169, 183, 302.
Carbon dioxide as an agent in extinguishing mine fires, with special reference to its application at Senghenydd colliery, 209.—Discussion, 237.
—, summary and conclusions, 234.
Carboniferous period, physiography of north-western Europe during, 101.
Carlow, Charles, *health of old colliers*, 482.
Carnegie, Andrew, quoted 360.
Carrington, T., quoted, 656.
Cast steel, analyses, 253.
Cement-mortar for brick-walling in shafts, 311.
Chains, admiralty tests for, 255.
—, reannealing of, 255.
Chains for cage attachments, specification of material for, 254.
Chairman's address, 462.
Chambers, W. H., quoted, 235.
Charnian axis, North Midland coalfield and, 442.
Charnian folds, European coalfields, 102.
Chesneau, G., quoted, 685, 692.
Chesneau firedamp detecting lamp, 684.
Chesterfield and Midland Counties Institution of Engineers, list of papers on safety-lamps, 714.
Chèvremont safety-lamp, 592, 595.
Clanny, William Reid, memoir of, 561.
—, presentation to, 568.
—, quoted, 558, 559, 560, 562, 578, 607.
Clanny safety-lamps, 562, 599, 605, 606.
Clanny type safety-lamps, list, 700.
Clark, H. H., quoted, 71.
Clark, William, quoted, 614.
Clarke, —, quoted, 117, 136.
Clayton, John, quoted, 557.
Cleghorn, Joseph, quoted, 563.
Clement, John, election, N.E., 35.
Clifford, W., quoted, 666.
Clive, R., and W. C. Blackett, quoted, 381.
Clowes, Frank, and Boverton Redwood, quoted, 209.
Clowes firedamp detecting lamp, 685.
Coal, absorption of oxygen by, anthracite, 517.
—, —, Ayrshire coals, 528.
—, —, barnsley coal, 514.
—, —, bullhurst seam, 525.
—, —, chemical composition of coal and, 530.
—, —, Durham coals, 520.
—, —, lignite, 527.
—, —, —, carbon dioxide evolved, 529.
—, —, measurement of oxygen absorbed, 512.
—, —, methods of analysis, 511.
—, —, moisture and, 530.
—, —, Northumberland coals, 520.
—, —, oxygen percentage in air and, 496.
—, —, rates for different finenesses, 494.
—, —, rates for different varieties of coal, 510.
—, —, rates for varying oxygen percentages, 497.
—, —, size of coal-particles and, 493.
—, —, spontaneous heating and size of particles, 495.
—, —, Staffordshire thick coal, 526.
—, —, taking of samples, 511.
—, —, Welsh steam coals, 519.
—, analyses, Ayrshire, 528.
—, —, bullhurst seam, 525.
—, —, Durham, 520.
—, —, lignite, Portrush, 527.
—, —, Northumberland, 520.

Coal, analysis, Staffordshire thick, 526.
—, —, Welsh steam, 519.
—, analysis, 511.
—, bye-products from, increasing importance, 95.
—, distillation of, combustible gases evolved, 217.
—, inferior, enhanced value of, 95.
—, moisture in, estimation, 484, 535, 543.
—, —, geological age of seams and, 538.
—, —, mode of occurrence, 534.
—, selling price of, restricted output and, 51.
—, small, comparison for steam-raising and coke manufacture, 460.
—, spontaneous heating of, heights of stacks and, 544, 546.
—, —, oxygen contents and, 531.
—, sulphur in, mode of occurrence, 512, 533.
Coal-cutting machines, American, tests in British collieries, 56, 340.
—, compressed air for, 157.
—, electrical, naked cables and, 340 *et seq*, 387.
—, output from, 43.
—, shortwall, 340 *et seq*.
—, United Kingdom, longwall workings and, 464.
—, U.S.A., 35 *et seq*.
Coal-dust, harmless effect on lungs of, 475.
Coal-dust explosions, air-pressures and, 401.
—, influence of incombustible substances on, 369, 401.
—, —, apparatus used, 369.
—, —, carbon-dioxide evolutions and, 372.
—, —, comparison of various substances with lime as unit, 377.
—, —, fineness of inert dusts and, 381.
—, —, fineness of material used, 370.
—, —, heat of reaction and, 374.
—, —, ignition by Nernst filaments, 370.
—, —, least effective percentages of various quenching materials, 371.
—, —, specific heat of quenching material and, 372, 379.
—, —, —, curves, 375, 376.
—, —, water of crystallization and, 373.
—, —, water vapour and, 372.
—, pioneering cloud in propagation of, 401.
Coalfields, British Columbia, valuation of, 244.
—, concealed, southern England, 141.
—, continental, resurvey of, 100.
—, dip of, early explanations, 410.
—, European north-western connexion between, 99, 266.
Coalfields, Kent, geology, 99, 137.
—, Sheffield and neighbouring, effects of earth-movements, 409.
—, —, preparation of geological map, 412.
—, U.S.A., valuation of, 244.
Coal industry, bye-products, national importance of, 466.
Coal-measures, Croxteth Park inlier, 91.
—, earth-movements and, south Yorkshire and neighbouring coalfields, 207.
Coal-miners, health of, fumes from explosives and, 483.
—, —, housing conditions and, 479.
—, —, rates of wages and, 477.
—, old, liability to bronchitis, 473.
Coal-mines, lighting of, previous tc invention of safety-lamp, 550.
Coal-mines inspection act, 1855, 628.
Coal-mines regulation act, safety-lamps and, 1872, 634.
—, —, 1887, 652.
—, —, 1896, 687.
—, —, 1911, 687.
Coal-mining, Committee of the Advisory Council for Scientific and Industrial Research, list of members, 463.
—, health of workers, 469.
—, natural conditions, United Kingdom compared with U.S.A., 389.
—, pillars for surface support, waste due to, 467.
—, United Kingdom, review of present-day practice and conditions, 464.
—, U.S.A., 35, 340, 386, 458.
Coal-output, per man, U.S.A., 45.
—, —, United Kingdom, reasons for decline, 53.
—, —, statistics, 51.
Coal-seams, deposition during Carboniferous period, 109.
Coal-tar, uses of, 466.
Coal-tar industry, Germany and, 204.
Coal-washing, economies in, 268.
—, —, classification after washing, 286.
—, —, continuous plants, 273, 274, 275.
—, —, delivery of coal to washeries, 281.
—, —, drainage-bunkers, 268.
—, —, dust in coal and, 282 *et seq*.
—, —, intermittent plants, 277, 278.
—, —, labour saving devices, 272.
—, —, limits attainable, 268.
—, —, limits of size of coal treated, 282.
—, —, slurry-recovery, 268.
—, —, slurry-refiner, 272.
—, —, storage capacity, coke-oven supplies and, 279.
—, —, washing-water, effects of continued use, 282 *et seq*.

Coalbrookdale coalfield, Symon fault, origin, 117.
Cobb, John W., and Harold Hollings, quoted, 531.
Cockerill & Company, John, Liége, quoted, 662.
Coke, manufacture of, bye-products from, 204.
—, —, —, national importance of, 466.
—, —, low-temperature distillation of coal and, 205.
—, —, storage capacity of coal-washers and, 279.
Coke-oven gases, quantity available, United Kingdom, 467.
—, residual, applications, 205.
Coke-ovens, beehive, national loss of bye-products, 467.
Collier, Price, quoted, 361.
Colliers, old, health of, 469.
—, —, liability to bronchitis, 473.
Collis, Edgar L., *health of old colliers*, 482.
Combes, Ch., quoted, 602.
Combes safety-lamp, 615.
Commentry, France, experiments on mining timber, 198.
Compressed air, after-coolers for, 7.
—, high-speed air-compressors for mining work, 2.
—, pipe-lines, 21.
—, —, formula for calculating size, 22.
Compressed air for coal-cutters.—Discussion, 157.
—, air-meters, surging of air and, 160.
—, docility of, 158.
—, efficiency, load-factor and, 160.
—, electrical power compared with, 158, 163.
—, explosions in air-receivers, 164.
—, pipe-lines, electrically welded, 159, 160.
—, —, plans of, 166.
Compressed air for coal-cutters, pressure-drop and velocity, 161.
—, pressure-gauges, position of orifice of, 161.
—, wire-drawing, 164.
Concrete Z-blocks, lining shafts with, 154.
—, —, cost, 155.
Connexions between north-western European coalfields, 99.—Discussion, 266.
Contours, geological, exterpolation of, 434.
—, —, plotting of, 412 *et seq.*
Conveyors, face, size of tubs and, 86, 88.
Copper sulphate, effect on mining timber, 196.
Cork, John, *high-speed air-compressors*, 28.
Correlation, coalfields, Kent, 138.
—, —, Midland, 115.
—, —, north-western European, 99.
Corrosion of iron and steel, 256.
Corrosive sublimate, effect on mining timber, 196.
Cort, Henry, quoted, 246.
Cortazar, D. de, quoted, 602, 623, 632, 671.
Coste, J. H., and G. N. Huntley, quoted, 484.
Council, vii.
—, election, S. I., 291.
Council's annual report, S.I., 288.
Crampton, —, and — Peach, quoted, 131.
Creosote, effect on mining timber, 197.
Cross, Tetley, & Company, quoted, 720.
Croxteth Park inlier, coal-measures, 91.
Cumberbatch, Isaac William, election, N.S., 1.
Cunynghame-Cadman firedamp detector, 686.

## D

Dalton, John, quoted, 552.
Dams, water, in coal, Netherseal colliery, 456.
Darlington, Daniel, election, M.G., 266.
Darlington, James, quoted, 239.
Daubrée, A., quoted, 654.
Daum, —, and — Mayer, quoted, 687.
Davy, Sir Humphry, memoir of, 576.
—, presentation to, 589.
—, quoted, 555, 558, 560, 567, 570, 573, 574, 591, 592, 593, 605, 614, 624, 635.
Davy, John, quoted, 555, 577, 589, 592.
Davy safety-lamps, 578 *et seq.*
Davy type safety-lamps, list, 699.
Dawkins, W. Boyd, quoted, 99, 133, 137, 139, 143.
Dean, Samuel, *logic of trams*, 354.
—, modern American coal-mining methods, with some comparisons.—Discussion, 35, 340, 386, 458.
—, quoted, 88, 389.
Death-rates, from phthisis, coal-miners, 476.
—, various age-periods, workers in coal-mines, 469.
Demeure safety-lamp, 684.
Denudation, European coalfields, 121.
Derbyshire coalfields, effects of earth-movements, 409.
Devenport, Christopher, election, N.E., 35.
Devon-Dinant syncline, formation of, 117.

Dewar, Henry, quoted, 556, 557.
Dickinson, C., description of water-dams in coal at Netherseal colliery.—Discussion, 456.
—, *modern American coal-mining methods*, 458.
Dixon, E. E. L., quoted, 100, 104, 115.
Dixon, H. O., *South Lancashire coal-field, etc.*, 97.
Dixon, Joshua, quoted, 552, 556, 557.
Dobinson, Robert Etherington, election, M.I., 189.
Dobson, Charles L., memoir of George May, 402
Drexel Institute, Philadelphia, tests on Hirsch electrical lamps, 69.
Dron, R. W., *absorption of oxygen by coal*, 540.
—, election, vice-president, S.I., 291.
—, *forming shaft-pillar in thin seams*, 166.
Dry rot, mining timber and, 193.
Dumesnil safety-lamp, 602.
Duncan, David, election, S.I., 291.
Dunn, Matthias, quoted, 554, 555, 560, 567, 568, 573, 578, 583, 606, 607, 620.
Dunnachie, Lieut. William J. N., death in action of, 289.
Durham coals, absorption of oxygen by, 520.
Dykehead colliery, Larkhall, shaft-sinking, 305.

E.

Earth-movements, preparing maps of, 412.
—, some effects of, on coal-measures of Sheffield district (South Yorkshire and neighbouring parts of West Yorkshire, Derbyshire and Nottinghamshire)—Part I.—Discussion, 207.—Part II., 409.—Discussion, 449.
Eckhardt safety-lamp, 630.
Economies in coal-washing, 268.—Discussion, 281.
Economy in fuel, advances in, 465.
—, colliery practice and, 466.
—, discussion on, M.C., 459.
Electrical locomotives, U.S.A., bare trolley-wires for, 42.
Electrical power, comparison with compressed air, 158, 163.
—, exhaust-steam, air-compression and, 26, 33.
—, underground, U.S.A., 49.
Electrical power at collieries, gaseous fuel and, 206.
Electrical safety-lamps, early forms, 614, 654.
—, Hirsch, 61, 350, 388.
—, —, instructions for charging, 66.
—, numbers of, in British mines, 677.
Electrically-driven air-compressors, efficiency, 11.
—, governing of, 12.
—, high-speed, 6.
—, lay-out of, 20.
Ell coal, Lanarkshire, pyrites in, 539.
Elliott, G., quoted, 627.
Elliott, Ralph, quoted, 596.
Ellison, C. C., *absorption of oxygen by coal*, 532.
Ellison, Cuthbert, quoted, 578.
Eloin safety-lamp, 617.
Eloin type safety-lamps, list, 701.
Endless-rope haulage, Dykehead colliery, 337.
Eskmeals station, tests on safety-lamps, 624, 688
Estimation of moisture in coal, 484.—Discussion, 532.
European coalfields, bibliography, 149.
European coalfields, Caledonian folds, 102.
—, Charnian folds, 102.
—, denudation, 121.
—, —, post-carboniferous period, 122.
—, —, stephanian period, 121.
—, hercynian folds, 103.
—, Kent, 137.
—, local descriptions, 125.
—, Malvernian folds, 104.
—, Malvernian range, 125.
—, north-western, connexion between, 99, 266.
—, physiography during carboniferous period, 101.
—, —, Devon-Dinant syncline, 117.
—, —, lower, 104.
—, —, lower coal-measure, 113.
—, —, middle coal-measure, 113.
—, —, millstone-grit, 112.
—, —, north Wales-Brabant anticline, 116.
—, —, pendleside, 110.
—, —, tournaisian, 104.
—, —, transition and upper coal-measure, 117.
—, —, upper, 109.
—, —, viséan, 106.
—, Shropshire, 134.
Evans, Edgar C., carbon dioxide as an agent in extinguishing mine fires, with special reference to its application at Senghenydd colliery, 209.—Discussion, 237.
Évasée outlets for fans, reduction of velocity by, 241.
Exhaust-steam, air-compressors, reciprocating, 8.
—, electrical power from, air-compression and, 26, 33.
—, —, suggested tandem driving of, 29.
—, turbo-compressors, considerations regarding, 8.
Experimental fan in mining laboratory, value of.—Discussion, 241.
Explosions, air-pressure and, 401.
—, coal-dust, influence of incombustible substances on, 369, 401.

Explosions, early references, flint-and-steel mill and, 554.
—, safety-lamps in high-velocity currents, early experiments, 626, 632, 633, 635, 647.
Explosions in air-compressors, cause, 31.
Explosions in air-receivers, 164.
Explosives, fumes from, health of coal-miners and, 483.

F.

Fähndrich, —, quoted, 615, 621, 622, 696, 698.
Fans, ventilating, évasée outlets for, reduction of velocity by, 241.
—, —, experimental, 241.
—, —, standardization of tests on, 243.
—, —, water-gauges, work performed and, 241.
Fatigue of iron and steel, reannealing and, 255.
Faulds, Alexander, *geological structure of south Lancashire coalfield*, 244.
—, *some effects of earth-movements*, 207.
Faults, adjustment-faults, 93.
—, Lancashire coalfield, south, 92.
—, phenomena of, 93.
—, underground fires and, 516.
Fayol, Henri, quoted, 197, 198, 199, 222, 238, 544.
Fearnsides, W. G., *pit-timber and its preservation*, 200.
—, some effects of earth-movement on coal-measures of Sheffield district (South Yorkshire and neighbouring parts of West Yorkshire, Derbyshire and Nottinghamshire).—Part I.—Discussion, 207.—Part II., 409.—Discussion, 449.
Felling colliery explosion, 1812, 559.
Fenwick, —, quoted, 578.
Ferrous sulphate, effect on mining timber, 196.
Fife Coal Company, Limited, quoted, 482.
Fife safety-lamp, 624.
Firedamp, combustion of, platinum and palladium and, Davy's discoveries, 586.
—, detection of, early references, 551, 614.
—, —, safety-lamps, Ashworth-Gray, 685.
—, —, —, Beard-Mackie indicator, 686.
—, —, —, Briggs' loop, 686.
—, —, —, Chesneau, 684.
—, —, —, Clowes, 685.
—, —, —, Cunynghame-Cadman device, 686.
—, —, —, low percentage tests, 721.
—, —, —, Pieler, 654, 670.
—, —, —, Stokes, 685.
—, early references to explosive nature of, 550.
—, growth of knowledge of composition and properties, 556.
Firedamp, properties of, Davy's researches, 579.
—, testing for blackdamp and, 184.
—, variation in composition, 722 *et seq.*
Fires, underground, Ayrshire collieries, 529, 537.
—, —, barometric fluctuations and, 228.
—, —, breathing action at, 212, 227.
—, —, carbon dioxide as extinguishing agent, 209.
—, —, —, absorption of oxygen by coal and, 210.
—, —, —, access of air and, 239.
—, —, —, analyses of gases at Senghenydd colliery, 237.
—, —, —, analytical control of operations, 215.
—, —, —, circulation in affected areas, 238.
—, —, —, fissures in strata and, 240.
—, —, —, plant, installation of, 213.
—, —, —, —, operation of, 221.
—, —, —, properties of gas and, 213.
—, —, —, proportion required, 210.
—, —, —, retention of heat by strata and, 240.
—, —, —, smoke-box, use of, 221.
—, —, —, summary and conclusions, 234.
—, —, —, temperature and water-gauge measurements, 225.
—, —, —, water-gauge and, 230.
—, —, conditions favourable to initiation of, 514.
—, —, factors influencing propagation of, 227.
—, —, faults and, 516.
—, —, fissures in strata and, 227.
—, —, humidity changes and, 229.
—, —, moisture in ventilation and, 547.
—, —, Northumberland and Durham coalfields, rarity of, 520.
—, —, pyrites in coal and, 501.
—, —, Senghenydd colliery, 210.
—, —, temperature changes and, 228.
—, —, ventilation changes and, 230.
—, —, water-gauge readings, barometric pressure variations and, 233.
—, —, —, temperatures and, 233.
Fletcher, J. E., quoted, 250.
Fletcher, Leonard R., *carbon dioxide for mine-fires*, 237.
—, *south Lancashire coalfield, etc.*, 97.
Flint-and-steel mill, invention of, 552.

Forest of Dean coalfield, geology, 141.
Forming shaft-pillar in thin seams.—Discussion, 166, 292, 457.
Forster, T. E., quoted, 619.
Foxwell, Geoffrey Edwin, election, M.I., 189.
Frameries safety-lamp testing-station, 688.
France, introduction of Davy lamps in, 594.
—, northern, physiography during carboniferous period, millstone-grit, 113.
—, —, —, pendleside, 110.
—, —, —, tournaisian, 106.
—, safety-lamp regulations, 1895, 693.
Frankford Arsenal, Philadelphia, tests on Hirsch electrical lamps, 69.
Franklin Coal & Coke Company, U.S.A., quoted, 388.
French Firedamp Commission, 1887, safety-lamps and, 692.
Friemann & Wolf, quoted, 698.
Fuel economy, advances in, 465.
—, centralization of power and, 459.
—, colliery practice and, 466.
—, discussion on, M.C., 459.
—, mechanical stokers and, 460.
—, utilization of small coal, 460.
Fumat safety-lamp, 672, 680.
Fungi, mining timber and, 190.

G.

Galloway, R. L., quoted, 548, 550, 553, 560, 589, 592, 594, 614.
Gannister mines, decay of mining timber in, 201.
Garforth, Sir William, *absorption of oxygen by coal*, 541, 545.
—, appointment on Coal-Mining Committee, 464.
—, chairman's address, 462.
Garswood Hall, safety-lamp tests at, 720.
Garwood, J., quoted, 100, 108, 129, 130.
Gases from coke-ovens, quantity available, United Kingdom, 467.
—, residual, applications, 205.
Gates for cages, detachable, Dykehead colliery, 333.
Gauges, mine-tracks, standardization, 83.
Geological Survey, earth-movements in Sheffield and neighbouring coalfields and, 409.
Geology, coalfields, European, north-western, 99, 266.
—, —, Lancashire, Croxteth Park inlier, 91.
—, —, —, south, 91, 244.
—, —, north midland, charnian axis and, 442.
—, —, Sheffield and neighbouring, earth-movements, 409.
—, —, —, pre-permian surface of coal-measures, 415.
—, —, —, preparation of map, 412.
—, Malvernian range, 125.
—, mountain-range formation, 145.
—, transverse folding, 146.
Germany, coal-tar industry in, 204.
—, iron and steel production, comparison with United Kingdom, 52.
—, physiography during carboniferous period, pendleside, 111.
—, safety-lamps in, 696.
Gerrard, John, *carbon dioxide for mine-fires*, 239, 240.
—, *health of old colliers*, 482.
Gerrard, John, quoted, 719.
—, *south Lancashire coalfield, etc.*, 94, 98.
Gibson, John, *forming shaft-pillar in thin seams*, 293.
—, *high-speed air-compressors*, 29.
—, logic of trams, 72.—Discussion, 84, 350, 388.
Gibson, Walcot, quoted, 100, 118, 120, 128, 145, 411, 412, 413, 425, 427, 431, 438, 448, 452.
Gil y Maestre, A., quoted, 602, 623, 632, 671.
Gill, John, *pit-timber and its preservation*, 203.
Gillieaux, Marcel, lining shafts with concrete Z-blocks.—Discussion, 154.
Gilligan, —, quoted, 113.
Gisborne, —, quoted, 615.
Glass Houghton & Castleford Collieries, Limited, turbo-compressors at collieries of, 8.
Glover and Cail safety-lamp, 625.
Gob-fires, carbon dioxide as extinguishing agent, 209.
—, conditions favourable to initiation of, 514.
—, factors influencing propagation of, 227.
—, moisture in ventilation and, 547.
—, Northumberland and Durham coalfields, rarity, 521.
—, pyrites in coal and, 500.
Godin, —, quoted, 631, 651.
Godwin-Austen, —, quoted, 99.
Goleuni, —, quoted, 612.
Goodchild, J. G., quoted, 123.
Gossart, —, quoted, 595.
Gould, George Donald, election, N.E., 339.
Goupillière, Haton de la, quoted, 647, 651, 655, 656, 672.
Governors, air-compressors, 11.
Gracht, W. Van Waterschoot Van der, quoted, 100.
Graham, John Patrick, election, S.I., 291.

Graham, J. T., quoted, 486.
Gray, —, quoted, 577, 578, 579, 583.
Gray, Thomas, quoted, 185, 724.
Gray-Ashworth-Hepplewhite safety-lamp, 677, 678.
Gray safety-lamps, 640, 678.
Gray type safety-lamps, list, 701.
Green, A. H., quoted, 409, 410, 411, 429, 430, 443, 447.
Green, Harold, election, M.G., 91.
Greener, T. Y., *American coal-mining methods*, 59, 348.
—, *coal-dust explosions*, 382.
Greenwell, G. C., quoted, 546.
Gregory, John, *high-speed air-compressors*, 23.
Gregory, John, *specification of iron and steel*, 257.
Gregory, T. W. D., *coal-dust explosions*, 377.
Greiner, —, quoted, 247.
Groom, Percy, pit-timber and its preservation, 190.—Discussion, 200.
Groom, T., quoted, 125, 126, 127.
Gruner, —, quoted, 603.
Guide-ropes, Dykehead colliery, 328.
—, —, details of glands and weights, 330.
Guides for cages, fixed, Dykehead colliery, 335.
Gurney, Goldsworthy, quoted, 555, 596, 597.

II.

Habets, A., quoted, 638, 641, 642, 643, 644, 645, 646.
Hailwood safety-lamp, 682.
Haldane, J. S., *absorption of oxygen by coal*, 537, 539.
—, appointment on Coal-Mining Committee, 464.
—, health of old colliers, 469.—Discussion, 477.
—, quoted, 169, 175, 185, 209, 216, 531.
Haldane, J. S., and F. G. Meachem, quoted, 210, 502.
Hall safety-lamp, 626.
Hamilton, James, *forming shaft-pillar in thin seams*, 167.
Hanlon, Henry Charles Hubert, election, N.E., 339.
Hann safety-lamps, 639, 668.
Harding, John Bruce, election, N.S., 245.
Hardwick, F. W., and L. T. O'Shea, history of the safety-lamp, 548.—Discussion, 718.
Hardy Patent Pick Company, Limited, election, subscribers, N.E., 386.
Hare, Samuel, *American coal-mining methods*, 56, 346.
Harger, John, quoted, 210, 226, 234.
Hartley, J. W., *high-speed air-compressors*, 27.
—, *specification of iron and steel*, 262.
Harzé, E., quoted, 608, 651.
Hatchett, C., quoted, 592.
Haulage, endless-rope, Dykehead colliery, 337.
—, endless-rope and main-and-tail compared, 37.
—, importance of, 352.
—, rail-tracks in British collieries, 50.
—, tubs, standardization, 72, 350, 388.
—, U.S A., shoots, 359.
Headgears, Dykehead colliery, 317.
—, iron and steel for, specification of, 253.
Health of old colliers, 469.—Discussion, 477.
Heim, —, quoted, 410.
Henderson safety-lamp, 624.
Henry, William, quoted, 557, 558.
Henshaw, A. M., *high-speed air-compressors*, 24.
—, *specification of iron and steel*, 264.
Hepplewhite, W. H., *forming shaft-pillar in thin seams*, 457.
—, *modern American coal-mining methods*, 458.
—, *water-dams in coal at Netherseal colliery*, 456.
Hepplewhite-Ashworth-Gray safety-lamp, 677.
Hercynian folds, European coalfields, 103.
Hickling, George, coal-measures of Croxteth Park inlier.—Discussion, 91.
—, geological structure of South Lancashire coalfield.—Discussion, 91, 244.
High-speed air-compressors for mining work, 2.—Discussion, 23.
Hind, Wheelton, quoted, 100, 111.
Hirsch, Hiram H., Hirsch portable electric lamp, 61.—Discussion, 350, 388.
Hirsch portable electric lamp, 61.—Discussion, 350, 388.
—, instructions for charging, 66.
Hiscox, G. D., quoted, 13.
History of the safety-lamp, 548.
Hodgson, John, quoted, 559, 578, 579, 583, 584.
Holland, J., quoted, 589.
Holland, Sir Thomas, appointment on Coal-Mining Committee, 463.
—, quoted, 244.
—, vote of thanks to, 463.
Holland, coalfields, prospecting, 100.
Holland & Williams safety-lamp, 670.
Hollings, Harold, and John W. Cobb, quoted, 531.
Holmes, J. H. H., quoted, 560, 562, 563, 564, 567, 573.

HOMER, C. J., quoted, 546.
Honorary secretary, viii.
HOOKE, ROBERT, quoted, 550.
HOPPER, ANTHONY, quoted, 563.
Horse-power of horses, 85.
HOWAT safety-lamp, 641.
—, deflector type, 677.
HOWDEN & THRESH safety-lamp, 628.
HOWE, —, 111.
HULL, E., quoted, 99, 129, 143, 148, 149, 411, 451.
HUMBOLDT, BARON FRIEDRICH ALEXANDER VON, quoted, 554, 555.
HUNTER, SHERWOOD, economies in coal-washing, 268.—Discussion, 281.
HUNTLEY, G. N., and J. H. COSTE, quoted, 484.
HUTCHINSON, JOHN, quoted, 619.
HUTCHINSON, WILLIAM, quoted, 552.
Hyde Lane colliery, big fault at, 96.
Hydraulic packing, shaft-pillars and, 168.
Hygrometers, tables for use with, 177.
HYSLOP, G. P., *high-speed air-compressors*, 26.

I.

Inbye air-compressors, electrically-driven, 33.
Inclination of seams, size of trams and, 73.
Indicator diagrams, air-compressor, 13, 14, 16.
Influence of incombustible substances on coal-dust explosions, 369.—Discussion, 377, 401.
INGHAM, ROBERT, quoted, 601.
Inspection of mines, governmental, introduction of, 620.
INSTITUTION OF MINING ENGINEERS, chairman's opening address, June meeting, 1916, 462.
—, general meetings, iii.
—, list of papers on safety-lamps, 716.
—, medal awarded to W. N. Atkinson, 462.
Intercoolers, high-speed air-compressors, design of, 6.
Iron and steel, corrosion of, 256.
—, distinction between, 246.
Iron and steel for colliery use, alternating and impact tests, 250.
Iron and steel for colliery use, analyses of various materials, 250, 253.
—, armco iron, 250.
—, classification, 246.
—, requirements, 249.
—, specification of, 245.
—, —, cages, 253.
—, —, chains, 254, 255.
—, —, rails underground, 253.
—, —, structural work, 253.
—, —, tub-bodies, 252.
—, —, tub-wheels and axles, 252.
—, wrought-iron, British standard tests, 258.
—, —, fatigue in, 255.
—, —, grades of, 251.
—, —, manufacture of, 246.
—, —, properties, 249.
Iron and steel production, Germany and United Kingdom compared, 52.
Iron pyrites, atmospheric oxidation of, 500, 532.
IRONSIDE, EDWARD ALLAN, election, M.I., 408.
IRVINE, A. K., quoted, 647.

J.

JACKSON, C. G., quoted, 719.
JARVIE, WILLIAM, election, councillor, S.I., 291.
JESSOP, —, quoted, 550, 556.
JOHNSON & ROUTLEDGE safety-lamp, 670, 673.
JOLY, —, quoted, 452.
JONES, ARCHIBALD EDWARD, election, M.G., 91.
JONES, O. T., quoted, 146.
JUKES, —, quoted, 114.
JUKES-BROWNE, A. J., quoted, 131.

K.

KENDALL, P. F., quoted, 99, 442, 443, 446.
—, *some effects of earth-movement*, 450.
Kent coalfield, correlation, 138.
—, geology, 99, 137.
Keps, winding, Dykehead colliery, 336.
KERR, G. L., *absorption of oxygen by coal*, 538.
—, quoted, 243.
Keuper period, denudation of European coalfields during, 124.
KIDSTON, R., quoted, 100, 118, 120.
KILPATRICK, WILLIAM M., *logic of trams*, 84.
KING, LIEUT. CAMPBELL, death in action of, 289.
KIRKBY, RICHARD, election, councillor, S.I., 291.
KIRKPATRICK, JAMES, *forming shaft-pillar in thin seams*, 295.
KLEIN, W. C., quoted, 149.
KLINGER, —, quoted, 554.
KREISCHER, G., quoted, 660.
KRESSMANN, —, and — PARR, quoted, 502.

## L

Laboratory, mining, value of experimental fans in, 241.
Laithewaite, Lieut. —, death in action of, 208.
Lambert, Richard, quoted, 591.
Lambton, J. G., quoted, 587, 589, 591.
Lamplugh, —, quoted, 422.
Lamps, electrical, Hirsch, 61, 350, 388.
Lanarkshire ell coal, pyrites and, 539.
Lancashire coalfields, Croxteth Park, geology, 91.
—, dip of, Wigan, 96.
—, south, geological structure, 91, 244.
—, washing of coal from, 284.
Land, Harry Stephen, election, M.C., 456.
Landau safety-lamp, 641.
Laporte, —, quoted, 594.
Lapworth, Charles, quoted, 99, 101, 114, 131, 132, 410, 445.
Le Chatelier, H., quoted, 654, 655, 657, 692.
Le Chatelier and — Mallard safety-lamp, 655.
Leakage tests, air-compressors, 14.
Lefrançois, —, quoted, 615.
Lefroy —, quoted, 594.
Legislation, coal-mining in United Kingdom and, 49.
—, safety-lamps and, 1888 to 1913, 675.
Lehigh Coal & Navigation Company, U.S.A., quoted, 388.
Lemaire, Emmanuel, quoted, 677.
Lemielle safety-lamp, 608.
Lever, Ellis, quoted, 650.
Levy, Leonard A., quoted, 217.
Lewis, William H., *modern American coal-mining methods*, 458.
Lighting of coal-mines previous to invention of safety-lamp, 550.
—, flint-and-steel mill, 552.
—, phosphorescent materials, 555.
Lignite, absorption of oxygen by, 527.
—, spontaneous heating of, 528.
Limestones, conditions during formation, 110.
Lining shafts with concrete Z-blocks. —Discussion, 154.
Lister, —, quoted, 550.
Lloyd, Edward, notes on uses and markets of bye-products obtained from coke-ovens.—Discussion, 204.
Lloyd, W. D., *pit-timber and its preservation*, 202.
Load-factor, efficiency of compressed air and, 160.
Locomotives, underground, British collieries and, 36.
—, —, gradient of roads and, 389.
—, —, use in thin seams, 359.
Logan, —, quoted, 117.
Logic of trams, 72.—Discussion, 84, 350, 388.
Lomax, James, quoted, 545.
Londonderry, Lord, quoted, 567.
Longwall workings, shaft-pillars and, 167.
—, United Kingdom, 464.
Loudon, George, election, N.E., 35.
Louis, Henry, *absorption of oxygen by coal*, 532, 534.
—, *coal-dust explosions*, 381.
—, *health of old colliers*, 477.
—, quoted, 377.
Louvre safety-lamp, 682.
Lowther, Sir James, quoted, 552, 556.
Lung disease, death-rates from, coal-miners, 470.
Lupton, Arnold, *health of old colliers*, 478.
—, *logic of trams*, 350.
—, *some effects of earth-movement*, 449, 452.
Lyell, —, quoted, 453.

## M.

McCreath, William, *forming shaft-pillar in thin seams*, 295.
Machine mining, bord-and-pillar workings, 340 *et seq.*
—, lay-out of mine and, 342.
—, United Kingdom, obstructive tactics of workmen to, 49.
—, —, tests with American machines, 56.
—, U.S.A., 35 *et seq.*
Mackay, Mungo, election, councillor, S.I., 291.
McKelvie, Lieut. David, Military Cross awarded to, 289.
Mackey, W. McD., *absorption of oxygen by coal*, 533, 534.
Mackworth safety-lamp, 625.
McLaren, Robert, *estimation of oxygen and blackdamp*, 302.
McLaren, Robert, *forming shaft-pillar in thin seams*, 292.
Malherbe, Renier, quoted, 595.
Mallard, M., quoted, 654, 655, 657.
Mallard and Le Chatelier safety-lamp, 655.
Malvernian folds, European coalfields, 104.
Malvernian range, geology of, 125.
Manchester Geological and Mining Society, general meetings, iii.
—, list of papers on safety-lamps, 711.
Marcasite, variety of iron pyrites, 533, 540, 541.
Marr, J. E., quoted, 108, 129.
Marsaut, J. B., quoted, 624, 631, 645, 647, 649, 650, 651, 652, 653, 655, 656, 657, 658, 664, 671, 672, 692, 719.
Marsaut safety-lamp, 658.

MARTIN safety-lamps, 599, 604.
MASTERTON, JOHN, election, vice-president, S.I., 291.
—, *estimation of oxygen and blackdamp*, 187.
MATHER, JAMES, quoted, 601.
MATSUBAYASHI, YASUKUMA, election, N.E., 35.
MAUD, JOHN, quoted, 556.
MAVOR, SAM, compressed air for coal-cutters.—Discussion, 157.
—, quoted, 23, 31.
MAVOR & COULSON, LIMITED, quoted, 42.
MAVROGORDATO, A., quoted, 475, 481.
MAY, GEORGE, memoir of, 402.
May Hill anticline, geology, 125.
MAYER, —, and — DAUM, quoted, 687.
MAYER, RALPH W., *logic of trams*, 358.
MEACHEM, F. G., quoted, 539.
MEACHEM, F. G., and J. S. HALDANE, quoted, 210, 502.
MEIN, HENRY JOHNSON, election, M.C., 456.
Meldrum furnaces for boilers, non-success of, 459.
MERIVALE, JOHN H., *American coal-mining methods*, 58.
Method for rapid estimation of oxygen and blackdamp in air of safety-lamp mines, 169.—Discussion, 187, 302.
MEYER, G. A., quoted, 682.
Midland coalfields, correlation, 115.
—, origin of, 114.
MIDLAND COUNTIES INSTITUTION OF ENGINEERS, general meetings, iv.
MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS, general meetings, iv.
—, list of papers on safety-lamps, 714.
MILBANKE, SIR RALPH, quoted, 559.
MILLS, J., quoted, 607.
Millstone-grit period, physiography of European coalfields during, 112.
Mine air, blackdamp and oxygen in, estimation, 169, 302.
Mine-cars, size of, in relation to output, 36 *et seq.*
—, standardization of, 72, 350, 388.
—, —, tracks for, 79.
Mine-gases, firedamp, variation in composition, 722.
Miner's electrical safety-lamp, Hirsch, 64, 350.
Miners, old, coal-mining, health of, 469.
—, —, —, liability to bronchitis, 473.
MINING INSTITUTE OF SCOTLAND, general meetings, iv.
—, list of papers on safety-lamps, 715.
Modern American coal-mining methods, with some comparisons.—Discussion, 35, 340, 386, 458.
Moisture in coal, estimation of, 484, 535, 543.
—, —, conclusions arrived at, 492.
—, —, heating in vacuo, 486.
—, —, reabsorption after drying, 491.
—, geological ages of seams and, 538.
—, mode of occurrence, 534.
Moisture in mine air, effect on workers, 176.
—, influence on blackdamp and oxygen determinations, 175.
—, table for determination, 177.
Moisture in mines, decay of timber and, 192.
—, effect on underground fires, 229.
—, spontaneous heating of coal and, 546.
MOODIE, JOHN, quoted, 569, 571.
MOORE, —, quoted, 615.
MOORE, ROBERT THOMAS, appointment on Coal-Mining Committee, 464.
MORGAN, C. L., and S. H. REYNOLDS, quoted, 125.
MORGAN, J. D., *coal-dust explosions*, 380.
MORGAN safety-lamp, 669.
MORISON safety-lamp, 646.
MORTON, JAMES, election, councillor, S.I., 291.
MOSTYN, ROGER, quoted, 550.
MOWAT, D. M., *absorption of oxygen by coal*, 538, 544.
—, *compressed air for coal-cutters*, 157.
—, election, president, S.I., 291.
—, *forming shaft-pillar in thin seams*, 168, 296.
—, *health of old colliers*, 478.
MUESELER safety-lamps, 599, 608.
MUESELER type safety-lamps, list, 700.
MULKAY, JOSEPH, quoted, 608.
MURCHISON, —, quoted, 99.
MURRAY, JAMES, quoted, 615.
MURRAY, JOHN, quoted, 567, 593, 596, 607.
MURRAY safety-lamp, 592.

N

NADIN, R., *pit-timber and its preservation*, 203.
Nanaimo coalfields, Vancouver island, valuation of, 244.
Nernst lamp filament, initiation of experimental coal-dust explosions by, 370.
Netherseal colliery, water-dams in coal at, 456.
New Modderfontein gold-mine, air-compressors, 19.
—, —, filtering-houses, 19.
New Moss colliery, big fault at, 92, 93.
NICHOLSON, A. D., quoted, 531.

Nisbet, James, sinking and equipment of circular shaft, 305.
Noble, Ernest Edward, election, N.E., 339.
Norfolk & Western Railway, U.S.A., capacity of railway-wagons, 358.
North, Roger, quoted, 551.
North of England Institute of Mining and Mechanical Engineers, general meetings, v.
—, list of papers on safety-lamps, 712.
North Staffordshire Institute of Mining and Mechanical Engineers, general meetings, v.
—, list of papers on safety-lamps, 715.
North Wales-Brabant anticline, formation, 116.
North-Western Improvement Company, U.S.A., quoted, 388.
Northumberland coals, absorption of oxygen by, 520.
Nottinghamshire coalfields, effects of earth-movements, 409.

O.

Officers, election, S.I., 291.
Oliver, William, election, N.E., 339.
Ollerenshaw, W., *south Lancashire coalfield, etc.*, 91.
Olry, —, quoted, 141.
Open-hearth steel, manufacture of, 247.
Orchard, A. J. A., *carbon dioxide for mine-fires*, 238.
Orsat apparatus for gas-analysis, 216.
O'Shea, L. T., *absorption of oxygen by coal*, 545.
—, *uses and markets of bye-products from coke-ovens*, 204.
O'Shea, L. T., and F. W. Hardwick, history of the safety-lamp, 548.
Oxidation of iron pyrites, 500, 532.
Oxygen, absorption by coal, 493, 510. —Discussion, 532.
Oxygen and blackdamp, estimation in safety-lamp mines, 169, 302.

P.

Packing, airtight, necessity for soft materials, 294.
—, hydraulic, shaft-pillars and, 168.
Palladium, combustion of firedamp and, Davy's discoveries, 586.
Parfitt, I. C., *logic of trams*, 388.
Paris, John Ayrton quoted, 578, 579, 582, 589, 590, 592.
Parr, —, and — Kressmann, quoted, 502.
Past-presidents, vii.
Paton, J. Drummond, *carbon dioxide for mine fires*, 237.
—, *economies in coal-washing*, 282, 284.
—, *south Lancashire coalfield, etc.*, 95.
Patterson, George, quoted, 563.
Patterson, William, quoted, 563.
Peace, W., quoted, 619.
Peach, —, and — Crampton, quoted, 131.
Peck, W. R., *logic of trams*, 352.
Pelton safety-lamp, 639.
Pendleside period, physiography of European coalfields during, 110.
Pennine Chain, geology, 128.
Pennsylvania Coal & Coke Corporation, U.S.A., quoted, 388.
Pennsylvania Railway, U.S.A., capacity of wagons, 358.
Pereira, Jonathan, quoted, 596, 597.
Permian period, denudation of European coalfields during, 123.
Peters, E. W., quoted, 190, 194, 197, 198, 199.
Phillips, John, quoted, 125, 128.
Phthisis, mortality from, breathing of harmful dust and, 475.
Physiography of north-western Europe during corboniferous period, 101, *et seq.*
Pickering, W. H., quoted, 457.
Pickering, W. H., and Basil Pickering, quoted, 293.
Pickup, W., *south Lancashire coalfield, etc.*, 97.
Pieler safety-lamp, 654, 670.
Pillars, shaft, steeply-inclined measures, 297.
Pillars for surface support, waste of coal due to, 467.
Pipe-lines, compressed air, 21.
Pipework, air-compressors, 15.
Pit-head framing, specification of iron and steel for, 253.
Pit-timber and its preservation, 190.—Discussion, 200.
Pittsburgh Buffalo Company, U.S.A., quoted, 388.
Planque, —, quoted, 612.
Plates, list of, vi.
Platinum, combustion of firedamp and, Davy's discoveries, 586.
Playfair, Lyon, quoted, 601, 619.
Ponson, A. T., quoted, 615, 617.
Poole, Granville, quoted, 531.
Porion safety-lamp, 640.
Portrush, lignite from, absorption of oxygen by, 527.
Post-carboniferous earth-movements, Sheffield and neighbouring coalfields, 409.
Power Plant Company, quoted, 9.
Power transmission, wave-motion, 58.
Pre-permian contours of Barnsley seam, 433.

Pre-permian earth-movements, Sheffield and neighbouring coalfields, 409.
Preservation of pit-timber, 190.
President, vii.
—, election, 462.
—, —, S.I., 291.
Prestwich, J., quoted, 99, 135, 137.
Price, Arthur F., election, S.I., 291.
Price, David, election, M.G., 266.
Pringle, J., quoted, 138.
Proctor, E., quoted, 142.
Protector Lamp & Lighting Company safety-lamps, 632.
Proutraux, A., quoted, 629.
Puddling process for manufacture of wrought-iron, 246.
Pumps, underground, shaft-pillars and, 168.
Purdy safety-lamp, 641.
Pyrites, atmospheric oxidation of, 500, 532.
—,—, heat produced by, 501.
—, —, —, measurement of, 503.
—, —, rate of, 504.
—, —, —, varying temperatures and, 508.
—, —, sulphate produced by, determination of, 513.
—, chemical properties and composition, 501.
—, crystalline forms, stability of, 500.
—, mineralogical species of, 532, 540, 541.
—, north Staffordshire coals, 505.
—, separation from coal, 533.
—, spontaneous heating of, comparison with barnsley coal, 509.
—, spontaneous heating of coal and, 500, 522 *et seq*, 532.

R.

Rabe & Wolf safety-lamp, 671.
Radiant energy in evolution of gases, 238.
Radio-activity, geological formations and, 452, 453.
Rails, underground tracks, standardization, 80.
Railway-wagons, U.S.A., capacity of, 358.
Raine, James, quoted, 559, 584.
Ramsay, —, quoted, 99, 123.
Ramsay, John Harry, election, N.E., 339.
Rand, air-compressors, filtering arrangements, 18.
—, turbo-compressor installations, 2.
Rayner, Sydney, election, M.G., 266.
Reading Coal & Iron Company, U.S.A., quoted, 388.
Redmayne, Sir R. A. S., quoted, 243.
Redwood, Boverton, and Frank Clowes, quoted, 209.
Reed, William Fenwick, election, N.E., 339.
Rees, W. T., quoted, 236.
Reflectors, Hirsch electrical lamp, 62.
Report of council, S.I., 288.
Reynolds, —, and — Morgan, quoted, 125.
Rhodes, C. E., quoted, 662, 721.
Richards, C. R., quoted, 21.
Riddell, William, *forming shaft-pillar in thin seams*, 167.
Riley Manufacturing Company, Limited, South Lambeth, quoted, 214.
Ritson, Lieut.-col. William Henry, election, N.E., 386.
Ritson, Major —, D.S.O. awarded to, 289.
Roadways, through shaft-pillars, maintenance of, 166.
Roberts, John, quoted, 596, 598.
Roberts & Upton safety-lamp, 598.
Robertson, David Wilson, election, N.E., 339.
Rock-drills, new system of operating, 163.
Roll of Honour, S.I., 289.
Room-and-rance method of working coal, 292.
Roscoe, —, and — Schorlemmer, quoted, 557.
Rosenkrantz safety-lamp, 672.
Ross, A., *carbon dioxide for mine-fires*, 239.
Rossigneux, —, quoted, 644, 645.
Routledge, W. H., *logic of trams*, 85.
Routledge, W. H., and J. A. Verner, quoted, 656.
Routledge & Johnson safety-lamp, 670, 673.
Royal Commission on Accidents in Mines, 1886, list of safety-lamps described, 699.
Royal Society, list of papers on safety-lamps, 709.
Royal Society of Arts, list of papers on safety-lamps, 710.
Rudge, W. A. Douglas, quoted, 402.
Russell, R., quoted, 409, 430, 443.
Russia, Emperor Alexander of, quoted, 589.
Ryan, James, quoted, 596.

S.

Safety-lamps, Ashworth-Gray type, development of, 719.
Safety-lamps, Ashworth-Hepplewhite Gray, 677.

Safety-lamps, Austrian Firedamp Commission, 1890, and, 686.
—, Barns, 679.
—, Belgian regulations regarding, 1851, 622.
—, —, 1904, 690.
—, Biram, 618.
—, Body-Firket, 681.
—, bonnets for, introduction of, 650.
—, Boty, 615.
—, Boty type, Bainbridge, 640.
—, —, Birckel, 671.
—, —, Eckhardt, 630.
—, —, Fife, 624.
—, —, Hann, 639.
—, —, list of, 701.
—, —, Porion, 640.
—, —, Saarbrücken, 629.
—, —, Winkler, 671.
—, —, Wolf, 671.
—, Brandling, 593.
—, British Royal Commission, 1906, and, 687.
—, Cambessédès, 679.
—, Chèvremont, 592, 595.
—, Clanny, blast-lamp, 562.
—, —, Davy type, 599, 604, 605, 606.
—, —, gas-light lamp, 566.
—, —, steam lamp, 565.
—, Clanny type, Cooke's, 624.
—, —, Evan Thomas, 667.
—, —, Flood, 639.
—, —, Henderson, 624.
—, —, list, 700.
—, —, Pelton, 639.
—, —, Schondoff, 671.
—, —, Simon, 639.
—, —, Wolf, 670.
—, —, Wood, 639.
—, —, Yates, 639.
—, coal-mines acts and, 1872, 634.
—, —, 1887, 652.
—, —, 1896, 687.
—, —, 1911, 687.
—, Combes, 615.
—, cuirasse de Gennes, 682.
—, Davy, 581.
—, —, adoption in continental countries, 595.
—, —, high-velocity explosive currents and, 596.
—, —, reflectors and lenses applied to, 599, 600.
—, Davy type, Adie & Simpson, 638.
—, —, Agre extinguishing arrangement, 599.
—, —, Ayre, 604.
—, —, Bourne, 629.
—, —, Clanny, 599, 604, 605, 606.
—, —, Cosset-Dubrulle, 617.
—, —, Daglish, 638.
—, —, Dillon, 600.
—, —, Dinant, 638.
—, —, Howden & Thresh, 628.
—, —, Jack, 621.
—, —, Laurent-Lermusiaux, 629.
Safety-lamps, Davy type, list, 699.
—, —, Martin, 604.
—, —, Newman, 599.
—, —, reflecting, 624.
—, —, Scotch, 620.
—, —, Simons, 623.
—, —, Stephenson, 638.
—, —, tin-can, 629.
—, —, Williams & Holland, 670.
—, Demeure, 684.
—, Dumesnil, 602.
—, electric, early forms, 614, 654.
—, —, Hirsch, 61, 350, 388.
—, —, numbers of, in British mines, 677.
—, Eloin, 617.
—, Eloin type, Buschmann, 672.
—, —, Fumat, 672, 680.
—, —, Gray, 640.
—, —, Hann, 668.
—, —, Howat, 641.
—, —, Landau, 641.
—, —, list, 701.
—, —, Purdy, 641.
—, —, Soar, 669.
—, —, Thornton, 625.
—, Eskmeals testing-station, 688.
—, —, results of test, 624.
—, firedamp detecting, Ashworth-Gray, 685.
—, —, Chesneau, 684.
—, —, Clowes, 685.
—, —, low percentage tests, 721.
—, —, Pieler, 670.
—, —, Stokes, 685.
—, Frameries testing-station, 688.
—, French Firedamp Commission, 1887, and, 692.
—, French regulations, 693 *et seq.*
—, Germany, 696.
—, Glover and Cail, 625.
—, Gray, 678.
—, Gray type, list of, 701.
—, Hailwood, 682.
—, Hall, 626.
—, high-velocity explosive currents, early experiments, 626, 627, 632, 633, 635, 647, 662, 665.
—, history, 548.
—, —, 1816 to 1835, 593.
—, —, 1836 to 1843, 600.
—, —, 1844 to 1866, 612.
—, —, 1867 to 1879, 630.
—, —, 1880 to 1887, 649.
—, —, 1888 to 1913, 674.
—, —, bibliography, 702.
—, Howat Deflector, 677.
—, internal explosions in, early conclusions regarding, 665.
—, internal relighters for, 675, 677.
—, legislation and, 1888 to 1913, 675.
—, Lemielle, 608.
—, locking of, 676.
—, —, lead-rivets for, invention, 626.
—, Louvre, 682.
—, Mackworth, 625.

Safety-lamps, Mallard and Le Chatelier, 655.
—, Marsaut, 658.
—, Marsaut's experiments on, 655.
—, Martin, 599.
—, miscellaneous types, list, 702.
—, Morgan, 668.
—, Morison, 646.
—, Mueseler, 599, 608.
—, Mueseler type, Arnould, 642, 643.
—, —, Barretta, 672.
—, —, Bay & Thys, 645.
—, —, Demanet, 642.
—, —, Godin, 642, 643.
—, —, Godin-Arnould, 644.
—, —, Goebel, 645.
—, —, Goffin, 644.
—, —, Harmegnies, 643.
—, —, Hislaire, 644.
—, —, Joassin, 642.
—, —, Lemielle, 611.
—, —, list, 700.
—, —, Marka, 645.
—, —, Morisson-Arnould, 643.
—, —, Mozart, 645.
—, —, Rocour, 612.
—, —, Rosenkrantz, 672.
—, —, Saint, 673.
—, —, St. Etienne, 636.
—, —, Smethurst, 673.
—, —, Souheur, 644.
—, —, Teale, 645.
—, —, Thomas, 645.
—, —, Thonard, 642.
—, Murray, 592.
—, Pieler, 654, 670.
—, priority of invention, 567, 590.
—, Protector Lamp & Lighting Company, 632.
—, refrigerating lamp, 600.
—, report of British Royal Commission on Accidents in Mines, 1887, 667.
—, Routledge & Johnson, 670, 673.
—, Scotch Davy, 620.
—, shut-offs for, introduction of, 653.
—, Sight, 682.
—, Stephenson, tube and slider form, 569.
—, —, tube form, 570.
—, Stephenson type, Evans, 629.
—, —, Hann, 668.
—, —, list, 700.
—, —, Smith, 604.
—, —, Williamson, 638.
—, testing for blackdamp and oxygen with, 169, 302.
—, Thorneburry, 679.
—, Upton & Roberts, 598.
—, Westphalian, 621.
—, Wilkins, 629.
—, Wolf, 684.
St. Germains colliery, analysis of blackdamp from, 173.
—, tests of apparatus for determining blackdamp and oxygen, 182.
Saint safety-lamp, 673.
Salmon, Thomas, quoted, 601.
Salt, effect on mining timber, 196.
Salter, J. W., quoted, 149.
Sawyer, A. R., quoted, 663.
Schmerber, H., quoted, 685.
Schmidt, F., quoted, 549.
Schondorff, —, quoted, 664, 686, 697, 698.
Schorlemmer, —, and — Roscoe, quoted, 557.
Scotland, coalfields, wash-outs in, 207.
Secretary, viii.
Senghenydd colliery, application of carbon dioxide for extinguishing underground fires at, 209, 210.
—, —, analyses of gases, 237.
—, —, water-gauge and, 230.
Sevens, William, *coal-dust explosions*, 382.
Shaft-pillars, forming in thin seams, 166, 292, 457.
—, —, complete removal of coal advocated, 292.
—, —, longwall workings and, 167.
—, —, ventilation and, 294.
—, hydraulic packing and, 168.
—, steeply inclined measures and, 297.
—, underground pumps and, 168.
Shaft-sinking, Dykehead colliery, 305.
—, —, banking arrangements at pit-bottom, 337.
—, —, brick-walling, 309, 310.
—, —, —, mortar used, 311.
—, —, bricking-scaffold, 312.
—, —, bricking-seat in clay, 309.
—, —, bricking-seat in metals, 315.
—, —, buffer-ropes, 328.
—, —, cage-seat and rope-weighting scaffold, 324, 325, 326.
—, —, cages, 331.
—, —, concrete surface support, 306.
—, —, crane for winding, 308.
—, —, doorhead lintels, 322.
—, —, fencing at pit-bottom, 338.
—, —, fencing at surface, 336.
—, —, guide-ropes, 328.
—, —, keps or shuts, 336.
—, —, kettle-strike, 317.
—, —, permanent fittings, 325.
—, —, plumbing, 308.
—, —, rings for temporary lining, 307.
—, —, selection of site, 305.
—, —, surface arrangements, 318.
—, —, ventilation, 323.
—, —, water-rings, 321, 322.
Shafts, lining of, concrete Z-blocks, 154.
Shaw, Edward, quoted, 236.
Sheffield district, coalfields, earth-movements, 409.
—, contours of barnsley seam, 421.
—, Don faults, 428.
—, pre-permian contours of barnsley seam, 433.
—, —, interpretation of statistical results, 439.
Shelton Iron, Steel, & Coal Company, Limited, quoted, 256, 261.

Sherfesee, W. F., quoted, 200.
Shoots, use in haulage, U.S.A., 359.
Shortwall coal-cutting machines, 340 *et seq.*
Shot-firing, U.S.A., Oklahoma, 40.
Shropshire coalfields, geology, 134.
Sibly, —, quoted, 100, 104, 125.
Siddall, Frank N., *economies in coal-washing*, 283.
Sight safety-lamp, 682.
Sim, John, *estimation of oxygen and blackdamp*, 187.
Simons, W., notes on specification of iron and steel suitable for colliery use, 245.—Discussion, 257.
Simons safety-lamp, 623.
Simpson, J. B., quoted, 549.
Sinking, lining of shafts during, 154.
Sinking and equipment of circular shaft, 305.
Sleepers, mine-tracks, standardization of, 80.
Sline, definition of, 446.
Smellie, Archibald, election, councillor, S.I., 291.
Smethurst, William, quoted, 608, 719.
Smiles, Samuel, quoted, 568, 570, 575, 592.
Smith, Sydney A., *south Lancashire coalfield, etc.*, 96.
Smith, William, *absorption of oxygen by coal*, 537.
—, *forming shaft-pillar in thin seams*, 292.
—, *logic of trams*, 88.
Smith safety-lamp, 604.
Smoke-box, testing for leakage at underground fires with, 221.
Sneddon, J. Balfour, *forming shaft-pillar in thin seams*, 295.
Soar safety-lamp, 669.
Somerville, Lord, quoted, 577.
Sommermeier, E. E., quoted, 502.
Sorby, H. C., quoted, 449, 453.
South Staffordshire and East Worcestershire Institute of Mining Engineers, list of papers on safety-lamps, 714.
South Wales, trams at collieries, 458.
South Wales Institute of Engineers, list of papers on safety-lamp, 718.
South Wales-Namur syncline, formation of, 117.
—, overthrust fault, 140.
Specific heats of inert dusts, coal-dust explosions and, 372.
Specification of iron and steel suitable for colliery use, 245.—Discussion, 257.
Spedding, Carlisle, quoted, 552.
Spontaneous heating of coal, chemical composition and, 530.
—, critical temperature, 238.
—, heights of stacks and, 544, 546.
—, lignite, 528.
—, moisture and, 546.
Spontaneous heating of coal, oxygen contents and, 531.
—, pyrites and, 500, 522 *et seq.*
—, size of particles and, 495.
Staffordshire, death-rates from bronchitis among old coal-miners, 475.
—, north, pyrites in coal from, 505.
—, south, coalfields, origin of, 114.
Stainier, X., connexion between north-western European coalfields, 99.—Discussion, 266.
—, quoted, 116, 124.
Stassart, S., and V. Watteyne, quoted, 633, 658, 660, 662, 688, 689, 697.
Steam-consumption, improvements in, 465.
Steel, manufacture of, acid and basic processes, distinction, 248.
—, —, Bessemer, 247.
—, —, Thomas & Gilchrist process, 248.
—, —, open-hearth, 247.
Steel and iron, distinction between, 246.
Steel and iron for colliery use, specification of, 245.
Steel and iron production, United Kingdom and Germany compared, 52.
Stephanian period, denudation of European coalfields during, 121.
Stephenson, George, memoir of, 568.
—, presentation to, 574.
—, quoted, 567, 568, 579, 590.
Stephenson, H., *carbon dioxide for mine fires*, 240.
—, *south Lancashire coalfield, etc.*, 96.
Stephenson, Robert, quoted, 568.
Stephenson safety-lamps, 569.
Stephenson type safety-lamps, list, 700.
Stevenson, —, quoted, 472.
Stirrup, Mark, quoted, 148.
Stobbs, —, quoted, 100.
Stoker, Arthur, *economies in coal-washing*, 284.
Stoker, John, election, N.E., 386.
Stokers, mechanical, for boilers, fuel economy and 460.
Stokes, A. H., quoted, 638.
Stokes firedamp testing lamp, 685.
Stone, Tom, *economies in coal-washing*, 285.
Stone-dust treatment of coal-dust, experiments on inert dusts, 369.
—, harmless effect of shale-dust on lungs, 475.
—, heat of reaction and, 374.
—, least effective percentage of various materials, 371.
—, potash-alum and, 380.
—, relative costs of various dusts, 382.
—, specific heat of inert dusts and, 372.

Stone-dust treatment of coal-dust, water of crystallization and, 373.
Strahan, A., quoted, 99, 108, 114, 117, 125, 129, 131, 132, 134, 137, 138, 139, 141, 142, 144, 145, 412, 426.
Strathmore Lord, quoted, 575, 574, 591.
Strike of strata, determination of, 417, 424.
Structural work at collieries, specification of iron and steel for, 253.
Subsidence, formation of shaft-pillars and, 296.
Suess, Edward, quoted, 101, 145, 410.
Sulphur in coal, mode of occurrence, 512, 533.
Summerlee Iron Company, Limited, sinking at Dykehead colliery, 305.
Sunderland, Society in, for Preventing Accidents in Coal Mines, formation of, 1813, 559.

T.

Tallis, J. Fox, quoted, 85.
Tar, uses of, 466.
Tate, Simon, *American coal-mining methods*, 44, 59.
Taylor, T. J., quoted, 613, 620, 626, 627.
Teall, —, quoted, 134.
Temperatures, underground, decay of mining timber and, 194.
—, —, effect of changes on underground fires, 228.
—, —, water-gauge readings and, 233.
Templeton, John Clark, election, N.E., 35.
Tennant, —, quoted, 558.
Thick coal, Staffordshire, absorption of oxygen by, 526.
Thin seams, forming shaft-pillars in, 166, 292, 457.
—, use of locomotives in, 359.
Thomas, David E., value of experimental fan in mining laboratory.—Discussion, 241.
Thomas, H. H., quoted, 146.
Thomas, John P., election, M.G., 266.
Thomas & Gilchrist process for manufacture of steel, 248.
Thomas safety-lamp, 667.
Thomson, T., quoted, 560, 566.
Thomson safety-lamp, 673.
Thorne, Mathew Henry, election, M.G., 91.
Thorneburey safety-lamp, 679.
Thorneycroft, Wallace, election, president, 462.
Thresh & Howden safety-lamp, 628.
Tilloch, Alexander, quoted, 572, 592, 593, 595.
Timber, mining, preservation of, 190.
—, —, —, antiseptics, 196.
—, —, —, chemical salts and, 194.
—, —, —, creosote and, 197.
—, —, —, creosoting under pressure, 199.
—, —, —, depth of mines and, 202.
—, —, —, dry rot and, 193.
—, —, —, durability after treatment with preservatives, 198.
—, —, —, durability of various kinds, 195.
—, —, —, fungi and, 190.
—, —, —, moisture and, 192.
Timber, mining, preservation of, temperature of mine and, 194.
Tortworth inlier, geology, 125.
Tournasian period, physiography of European coalfields during, 104.
Trade unionism, coal-mining in United Kingdom and, 53.
Track for trams, standardization, 79.
Treasurers, viii.
Trevelyan, Arthur, quoted, 584.
Trevelyan, Emma, quoted, 584.
Trimpley anticline, geology, 126.
Trotter, Thomas, quoted, 556, 557, 558.
Tubs, bodies of, material suitable for, 252.
—, brakes on, 357, 360.
—, economical design, importance of, 72.
—, friction and weight of, relative importance, 74.
—, rails for, advantages of wide gauge, 353.
—, —, practice in U.S.A., 395.
—, ratio of capacity to weight of load, 46.
—, size of, diameter of shafts and, 350.
—, —, face-conveyors and, 86, 88.
—, —, factors governing, 73, 350, 390.
—, —, manual labour and, 366.
—, —, minimum, 73.
—, —, relation to output, 36, 340, 349.
—, south Wales collieries, 458.
—, standardization of, 72, 350, 388.
—, —, manufacturers and, 366.
—, —, proposed scale, 75.
—, tracks for, gauges, 83.
—, —, standardization, 79.
—, turn-plates and flat-sheets for, objections, 355, 359.
—, useful life of, 58.
—, wheels for, size of, 392, 397.
Turbo-compressors, air-surging in pipework, 17.
—, considerations regarding, 8, 9.
—, efficiency, principle of turbines and, 32.
—, —, size of units and, 30.
—, Rand installations, 2.
Turnbull, John James, Jun., election, N.E., 339.

U.

United Kingdom, coalfields, physiography during carboniferous period, millstone-grit, 112.
—, —, —, pendleside, 111.
—, —, —, tournaisian, 104.
—, —, —, transition and upper coal-measure, 117.
—, —, —, viséan, 106.
—, coal-mining, present conditions compared with U.S.A., 363, 364.
—, —, review of present-day practice and conditions, 464.
—, coal-output per person employed, statistics, 51.
—, iron and steel production, comparison with Germany, 52.
—, underground locomotives at collieries, 36.
U.S.A., coalfields, valuation of, 244.
—, coal-mining methods, 35, 340, 386, 458.
—, —, haulage, importance of, 352.
U.S.A., coal-mining methods, heterogeneous labour in mines, 41.
—, —, locomotives, bare trolley-wires for, 42.
—, —, mine-cars, manual labour and, 391.
—, —, —, size of in relation to output, 36 *et seq.*, 340, 349.
—, —, mine-tracks, 395.
—, —, nomenclature, 390.
—, —, shot-firing, Oklahoma, 40.
—, coal-output, 45.
—, —, natural conditions and, 55, 59, 349, 389.
—, mining timber, cause of wastage, 190.
—, railway-wagons, capacity of, 358.
Upton, George, quoted, 596.
Upton & Roberts safety-lamp, 598.
Uses and markets of bye-products obtained from coke-ovens, notes on. —Discussion, 204.
Usk anticline, geology, 128.

V.

Valves, air-compressors, 4.
Vane, Lady Frances, quoted, 567.
Vaughan, —, quoted, 100.
Ventilation, changes in, effects on underground fires, 230.
—, driving through shaft-pillars and, 294.
—, fans, experimental, 241.
—, improved, bronchitis in old coal-miners and, 474.
Ventilation, shaft-sinking, Dykehead colliery, 323.
Verner, J. A., and W. H. Routledge, quoted, 656.
Vernon, R. D., quoted, 100, 118.
Vice-presidents, vii.
—, election, S.I., 291.
Viséan period, physiography of European coalfields during, 106.

W.

Waddell, Hugh, election, S.I., 291.
—, *estimation of oxygen and blackdamp*, 303.
—, quoted, 182.
Wailes, George, quoted, 571.
Wain, E. B., *specification of iron and steel*, 263.
Walford, —, quoted, 230.
Walker, G. Blake, *high-speed air-compressors*, 28.
—, quoted, 3, 206, 413.
Walshe, J. M., high-speed air-compressors for mining work, 2.—Discussion, 23.
Walters, Owen, election, M.I., 408.
Ward, Clifton, quoted, 100, 129.
Wardlaw, John B., election, S.I., 291.
Warrick, —, quoted, 615.
Wash-outs, Scottish coalfields, 207.
Washing of coal, economies in, 268.
Watchman's electric lamps, Hirsch, 61.
Water-dams in coal, Netherseal colliery, 456.
Water-gauges, fans, measurement of work performed and, 241.
—, measurements at underground fire, 211, 225, 230.
Water-rings, shaft-sinking, Dykehead colliery, 321, 322.
Water vapour in air, influence on estimation of blackdamp and oxygen in mine air, 175.
—, tables for estimating, 177.
Watkins, W. Gath, *fuel economy*, 460.
Watney, —, quoted, 130.
Watson, John, *logic of trams*, 86.
Watteyne, V., quoted, 723.
Watteyne, V., and S. Stassart, quoted, 633, 658, 660, 662, 688, 689, 697.
Watts, W. W., quoted, 142, 412.
Wave motion, power transmission by, 58.
Welch, —, quoted, 130.
Westmorland coalfields, origin of, 114.
Whalley, E. B., quoted, 185.
Wheeler, R. V., quoted, 217, 531, 624.
Wheels for pit-tubs, size of, 392, 397
—, specification of material for, 252.
Wheler, Francis Glynne, election, M.C., 456.
Wickens, —, quoted, 615.
Widdas, Henry, and P. Phillips Bedson, quoted, 369.

Wilkins safety-lamp, 629.
Wilkinson, James John, quoted, 559, 560, 567, 577, 597.
Williams & Holland safety-lamp, 670.
Williamson safety-lamp, 638.
Wilson, J. R. R., quoted, 531, 549, 593.
Wilson, James, quoted, 552.
Wilson, Lieut. James, death in action of, 289.
Wilson, W. B., Junr., *health of old colliers*, 483.
Winding, Dykehead colliery, permanent arrangements, 327.
—, —, sinking, 308.
Winding-engines, Dykehead colliery, 325.
Winding-ropes, Dykehead colliery, 335.
Winkler, Cl., quoted, 660.
Winkler safety-lamps, 671.
Winmill, T. F., absorption of oxygen by coal, 493, 510.—Discussion, 532.
—, atmospheric oxidation of iron pyrites, 500.—Discussion, 532.
—, estimation of moisture in coal, 484.—Discussion, 532.
Winmill, T. F., quoted, 210.
Winstanley, Robert, death of, 208.
Wire-drawing, compressed air, 164.
Wire-ropes, wear of pulleys and, 264.
Wolf Safety Lamp Company, Limited, quoted, 697.
Wolf safety-lamps, 670, 684.
Wollaston, W. H., quoted, 558, 592.
Wood, Nicholas, quoted, 552, 569, 570, 571, 596, 613, 619, 626, 627, 650, 719.
Wood, Percy L., *Hirsch portable electric lamp*, 350.
Wood, Sir Lindsay, quoted, 633, 639, 719.
Wood safety-lamps, 600, 639.
Woodward, A. S., quoted, 142.
Woodward Iron Company, U.S.A., quoted, 388.
Working, methods of, room-and-rance, 292.
Wrought-iron, British standard tests, 258.
—, grades of, 251.
—, manufacture of, 246.
—, properties of, 249.
Wyndus, Edward, quoted, 552.

Y.

Yorkshire coalfields, Sheffield and neighbouring districts, earth-movements, 207, 409.

Z.

Z-blocks, concrete, lining of shafts with, 154.
Zinc chloride, effect on mining timber, 197.

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Steam-condensation arrangements.
Steam-power plants.
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Subsidences caused by mining operations.
Surface-arrangements at mines.
Surveying and surveying instruments.
Transport on roads.
Tunnelling methods and appliances.
Underground conveyors.
Utilization of dust and refuse-coal.
Ventilation of coal-cargoes.
Water as a motive-power in mines.
Water-incrustations in boilers, pumps, etc.
Water-tube boilers.
Watering coal-dust.
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**See page ix. for detailed Contents of Part.**

## CONTENTS.

| | PAGE. |
|---|---|
| "High-speed Air-compressors for Mining Work." By Mr. J. M. Walshe, A.M.I.E.E. | 2 |
| "The Hirsch Portable Electric Lamp." By Mr. Hiram H. Hirsch ... ... ... | 61 |
| "The Logic of Trams." By Mr. John Gibson | 72 |
| "The Connexions Between the North-Western European Coalfields." By Prof. X. Stainier, D.Sc. ... ... ... ... | 99 |
| "A Method for the Rapid Estimation of Oxygen and Blackdamp in the Air of Safety-lamp Mines." By Mr. Henry Briggs ... ... ... ... ... | 169 |

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1916

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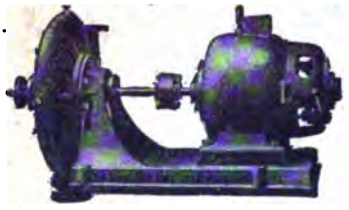

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[Ser. 2—Feb 13.

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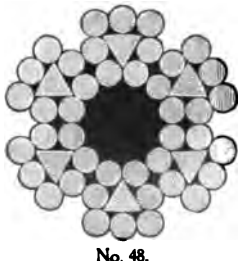

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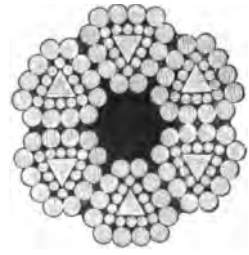

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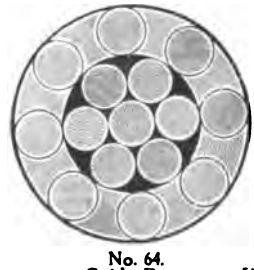

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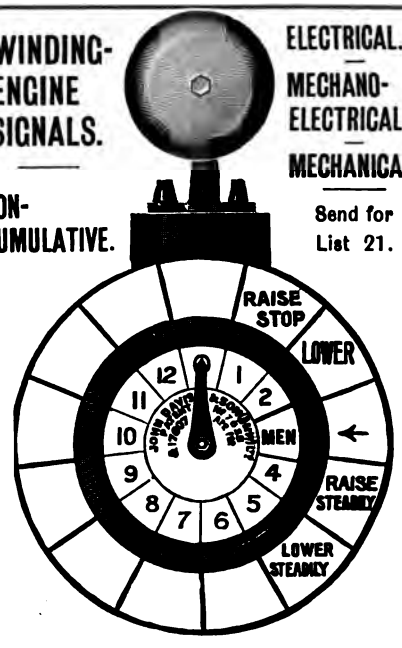


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## ADDRESSES WANTED.

—Notices and *Transactions* addressed to the following members at the addresses given have been returned by the Post Office. Any information as to the present addresses of any of these gentlemen, so that communications may be forwarded, will be welcomed by the Secretary. In order to obviate such occurrences, members are requested to notify the Secretary of their own Institute, as well as of The Institution of Mining Engineers, immediately of any change of address.

**Mr. William Armstrong**, late of 44, Main Street, Carronshore, Falkirk.

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**Mr. Samuel Baillie**, late of Parkfield Colliery, Pucklechurch, Bristol.

**Mr. Ellis Barraclough**, late of 343, Bolton Road, Pendlebury, Manchester.

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**Mr. Willis Beckett**, late of 20, Gregory Street, Ilkeston, Derbyshire.

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# VOL. LI. CONTENTS. PART 1.

PAGE.

THE NORTH STAFFORDSHIRE INSTITUTE OF MINING AND MECHANICAL ENGINEERS:—
General Meeting, Stoke-on-Trent, January 17th, 1916 ... ... ... ... 1
Institute Roll of Honour ... ... ... ... ... ... ... ... 1
"High-speed Air-compressors for Mining Work." By J. M. Walshe, A.M.I.E.E. ... ... ... ... ... ... ... ... ... ... 2
Discussion ... ... ... ... ... ... ... ... ... ... 23

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS:—
General Meeting, Newcastle-upon-Tyne, February 12th, 1916 ... ... ... 35
Discussion of Mr. Samuel Dean's paper on "Modern Coal-mining Methods, with some Comparisons" ... ... ... ... ... 35
"The Hirsch Portable Electric Lamp." By Hiram H. Hirsch ... ... 61
"The Logic of Trams." By John Gibson ... ... ... ... ... 72
Discussion ... ... ... ... ... ... ... ... ... 84

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY:—
General Meeting, Manchester, February 8th, 1916 ... ... ... ... ... 91
Discussion of Dr. George Hickling's papers on "The Coal-Measures of the Croxteth Park Inlier" and "The Geological Structure of the South Lancashire Coalfield" ... ... ... ... ... ... ... 91
"The Connexions Between the North-Western European Coalfields." By Prof. X. Stainier, D.Sc. ... ... ... ... ... ... ... 99

THE MINING INSTITUTE OF SCOTLAND:—
General Meeting, Edinburgh, February 12th, 1916 ... ... ... ... 154
Discussion of Mr. Marcel Gillieaux's paper on "Lining Shafts with Concrete Z-Blocks" ... ... ... ... ... ... ... ... 154
Discussion of Mr. Sam Mavor's paper on "Compressed Air for Coal-cutters" ... ... ... ... ... ... ... ... ... ... 157
Discussion of Mr. James Black's paper on "Forming a Shaft-pillar in Thin Seams" ... ... ... ... ... ... ... ... ... 166
"A Method for the Rapid Estimation of Oxygen and Blackdamp in the Air of Safety-lamp Mines." By Henry Briggs ... ... ... ... 169
Discussion ... ... ... ... ... ... ... ... ... 187

*Contents continued on page x.*

THE INSTITUTION OF MINING ENGINEERS.

# NOTICE.

All Members, Associate Members, Associates, or Students of The Institution of Mining Engineers, of

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[15

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A limited number of advertisements of engineering, etc., firms may be inserted in the *Transactions.* Applications for terms, etc., should be made to the Secretary, The Institution of Mining Engineers, Albany Buildings, 39, Victoria Street, Westminster, London, S.W.

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Notice of the Publication of each Part of the *Transactions* is contained in the first subsequent circular issued to the Members, and in case of non-receipt, immediate intimation should be given to the Secretary. Duplicate copies of any Parts can only be supplied to Members on payment of 5s. each, plus postage, but cannot even then be had if the Parts have been stitched together into volumes.

CONTENTS CONTINUED FROM PAGE IX.


| | PAGE. |
|---|---|
| ADDRESSES WANTED ... ... ... | viii |
| ADVERTISEMENTS IN TRANSACTIONS ... | ix, x |
| BINDING OF TRANSACTIONS ... ... | vi |
| BYE-LAW 9 ... ... ... ... | xii |
| CHANGE OF ADDRESS ... ... ... | viii |
| COPYRIGHT ... ... ... ... | ix |
| CORRESPONDING SOCIETIES ... ... | ... |
| ENEMY ALIEN MEMBERS ... ... | ix |
| ENGINEERING INSTITUTIONS' VOLUNTEER ENGINEER CORPS ... ... | ... |
| FORMATION OF A LIBRARY ... ... | ... |
| IMPORTANT NOTICES TO MEMBERS | iv, vi, viii, ix, x, xii |
| INDEX OF ENGINEERING SPECIALITIES | xii, xiii |
| INSTITUTION ROLL OF HONOUR ... | x |
| ISSUE OF TRANSACTIONS ... ... | x |
| LETTING OF COUNCIL CHAMBER ... | ... |
| LIST OF ADVERTISERS ... ... ... | xi |
| LIST OF FEDERATED INSTITUTES ... | ... |
| LIST OF OFFICERS & COUNCIL, 1915-1916 | ... |
| MINISTRY OF MUNITIONS ... ... | ... |
| NOTICE TO ADVERTISERS ... ... | ... |
| NOTICE TO AUTHORS ... ... ... | ... |
| PRINTED ADDRESS LABELS ... ... | xii |
| PUBLICATIONS ... ... ... ... | xii |
| SALE OF TRANSACTIONS .. ... | ... |
| TRANSACTIONS WANTED ... ... | xii |
| TUNNELLING COMPANIES, ROYAL ENGINEERS ... ... ... ... | iv |


*Contents continued on page xi.*

### Reading-and-Writing Room.

The Offices of the Institution are situated within a few minutes' walk of the Houses of Parliament, and include Secretary's and Clerks' Offices, and a Council Chamber fitted up as a Reading-and-Writing Room for the convenience of Members. The Secretary is in attendance from 10 a.m. to 5 p.m. (Saturdays 10 a.m. to 1 p.m.), and will give every assistance to Members visiting the Chambers.


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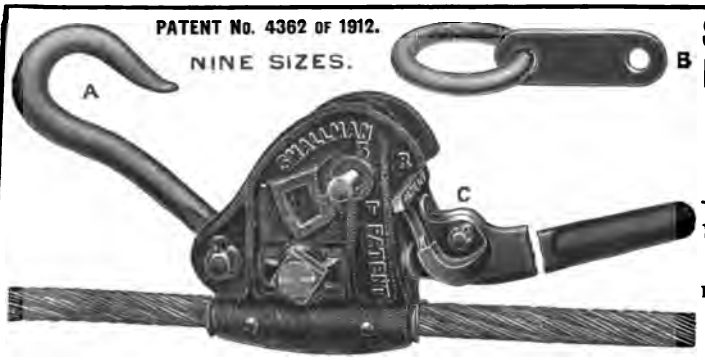
## LIST OF ADVERTISERS.


| | PAGE. |
|---|---|
| Allan, Whyte, & Co., Clyde Patent Wire-rope Works, Rutherglen, Glasgow ... ... | iii |
| Armstrong College, Newcastle-upon-Tyne ... ... ... ... ... ... ... | vi |
| Bullivant & Co., Ltd., 72, Mark Lane, London, E.C. ... ... ... ... ... | xv |
| Cooke & Co., William, Limited, Tinsley Steel, Iron, and Wire-rope Works, Sheffield ... | iv |
| Curtis's & Harvey, Limited, Cannon Street House, London, E.C. ... ... ... | ii |
| Davidson & Co., Ltd., "Sirocco" Engineering Works, Belfast ... ... ... ... | vii |
| Davis, John, & Son (Derby), Ltd., All Saints' Works, Derby ... ... ... ... | vi |
| Diamond Coal-cutter Co., Stennard Works, Wakefield ... ... ... ... ... | iii |
| Fletcher, George, & Co., Ltd., Masson and Atlas Works, Derby ... ... ... ... | vi |
| Hadfields, Limited, Sheffield ... ... ... ... ... ... ... ... | xvi |
| Henzell Oil Co., Northern Oil Works, Forth Banks, Newcastle-upon-Tyne ... ... | xiv |
| Mavor & Coulson, Limited, 47, Broad Street, Mile-End, Glasgow ... ... ... | vii |
| Pulsometer Engineering Company, Ltd., Nine Elms Iron Works, Reading ... ... | ii |
| Roburite and Ammonal, Limited, 103, Cannon Street, London, E.C. ... ... ... | v |
| Smallman, James W., Nuneaton ... ... ... ... ... ... ... | xi |
| Thornton, Ltd., A. G., Paragon Works, 64, King Street West, Manchester .. ... | ... |
| Universal Mining School, Cardiff ... ... ... ... ... ... ... ... | ix |
| Walker Bros. (Wigan), Ltd., Wigan ... ... ... ... ... ... ... ... | xi |
| Wright, J. & E., Ltd., Universe Works, Birmingham ... ... ... ... ... | v |


*If the page number is absent, the advertisement does not appear in this issue.*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Anyone having copies of Vols. III. and IV. (or portions thereof) for sale, will oblige by sending particulars, with price, to the Secretary, The Institution of Mining Engineers, Albany Buildings, 39, Victoria Street, Westminster, London, S.W.

# INDEX OF ENGINEERING SPECIALITIES.

*The advertisements of the firms mentioned under each heading can be found by referring to the List of Advertisers on page xv.*


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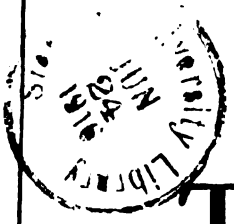

# Transactions OF The Institution OF Mining Engineers.

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**Pages 189 to 384.**

**Plates IV. and V.**

**See page ix. for detailed Contents of Part.**

## CONTENTS.

PAGE.

"...it-Timber and Its Preservation." By Prof. Percy Groom, M.A., D.Sc. ... ... 190

"Carbon Dioxide as an Agent in Extinguishing Mine Fires, with Special Reference to Its Application at the Senghenydd Colliery." By Mr. Edgar C. Evans, B.Sc., F.I.C. ... ... ... ... 209

"Notes on the Specification of Iron and Steel Suitable for Colliery Use." By Mr. W. Simons ... ... ... ... 245

"Economies in Coal-washing." By Mr. Sherwood Hunter ... ... ... 268

"The Sinking and Equipment of a Circular Shaft." By Mr. James Nisbet ... 305

"The Influence of Incombustible Substances on Coal-dust Explosions." By Mr. A. S. Blatchford, M.Sc. ... ... ... 369

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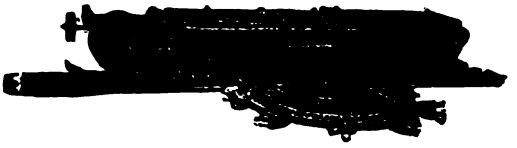

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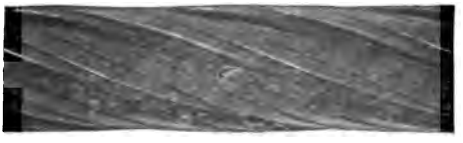

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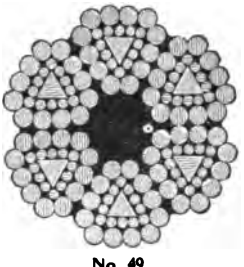

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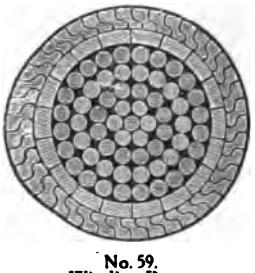

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# VOL. LI. CONTENTS. PART 2.

PAGE.

THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS:—
General Meeting, Leeds, March 21st, 1916 ... 189
"Pit-Timber and Its Preservation." By Prof. Percy Groom, M.A., D.Sc. 190
Discussion ... 200
Discussion of Mr. Edward Lloyd's "Notes on the Uses and Markets of Bye-products Obtained from Coke-ovens" ... 204
Discussion of Prof. William George Fearnsides's Paper on "Some Effects of Earth-movement on the Coal-Measures of the Sheffield District (South Yorkshire and the Neighbouring Parts of West Yorkshire, Derbyshire, and Nottinghamshire)" ... 207

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY:—
General Meeting, Manchester, March 14th, 1916 ... 208
Death of Mr. Robert Winstanley and Lieutenant Laithewaite ... 208
"Carbon Dioxide as an Agent in Extinguishing Mine Fires, with Special Reference to Its Application at the Senghenydd Colliery." By Edgar C. Evans, B.Sc., F.I.C. ... 209
Discussion ... 237
Discussion of Mr. David E. Thomas's Paper on "The Value of the Experimental Fan in the Mining Laboratory" ... 241
Discussion of Dr. George Hickling's Paper on "The Geological Structure of the South Lancashire Coalfield" ... 244

THE NORTH STAFFORDSHIRE INSTITUTE OF MINING AND MECHANICAL ENGINEERS:—
General Meeting, Stoke-on-Trent, March 27th, 1916 ... 245
"Notes on the Specification of Iron and Steel Suitable for Colliery Use." By W. Simons ... 245
Discussion ... 257

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY:—
General Meeting, Manchester, April 11th, 1916 ... 266
Discussion of Prof. X. Stainier's Paper on "The Connexions between the North-Western European Coalfields" ... 266
"Economies in Coal-Washing." By Sherwood Hunter ... 268
Discussion ... 281

THE MINING INSTITUTE OF SCOTLAND:—
Annual General Meeting, Glasgow, April 8th, 1916 ... 288
Annual Report of the Council, 1915-1916 ... 288
Accounts ... 290
Election of Officers, 1916-1917 ... 291
Discussion of Mr. James Black's Paper on "Forming a Shaft-pillar in Thin Seams" ... 292
Discussion of Mr. Henry Briggs's Paper on "A Method for the Rapid Estimation of Oxygen and Blackdamp in the Air of Safety-lamp Mines" ... 302
"The Sinking and Equipment of a Circular Shaft." By James Nisbet ... 305

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS:—
General Meeting, Newcastle-upon-Tyne, April 8th, 1916 ... 339
Discussion of Mr. Samuel Dean's Paper on "Modern American Coal-mining Methods, with Some Comparisons" ... 340
Discussion of Mr. Hiram H. Hirsch's Paper on "The Hirsch Portable Electric Lamp" ... 350
Discussion of Mr. John Gibson's Paper on "The Logic of Trams" ... 350
"The Influence of Incombustible Substances on Coal-dust Explosions." By A. S. Blatchford, M.Sc. ... 369
Discussion ... 377

*Contents continued on page x.*

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(17

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## CONTENTS CONTINUED FROM PAGE IX.


| | PAGE. |
|---|---|
| ADDRESSES WANTED ... ... ... | viii |
| ADVERTISEMENTS IN TRANSACTIONS ... | ix, x |
| BINDING OF TRANSACTIONS ... ... | vi |
| BYE-LAW 9 ... ... ... ... | xii |
| CHANGE OF ADDRESS ... ... ... | viii |
| COPYRIGHT ... ... ... ... | ix |
| CORRESPONDING SOCIETIES ... ... | x |
| ENEMY ALIEN MEMBERS ... ... | vi |
| ENGINEERING INSTITUTIONS' VOLUNTEER ENGINEER CORPS ... ... ... | ... |
| FORMATION OF A LIBRARY ... ... | ... |
| IMPORTANT NOTICES TO MEMBERS | iv, vi, viii, ix, x, xii, xvi |
| INDEX OF ENGINEERING SPECIALITIES | xii, xiii |
| INSTITUTION ROLL OF HONOUR ... | x |
| ISSUE OF TRANSACTIONS ... ... | x |
| LETTING OF COUNCIL CHAMBER ... | ... |
| LIST OF ADVERTISERS ... ... ... | xi |
| LIST OF FEDERATED INSTITUTES ... | ... |
| LIST OF OFFICERS & COUNCIL, 1915-1916 | ... |
| MINISTRY OF MUNITIONS ... ... | ... |
| NOTICE TO ADVERTISERS ... ... | ... |
| NOTICE TO AUTHORS ... ... ... | ... |
| PRINTED ADDRESS LABELS ... ... | xii |
| PUBLICATIONS ... ... ... ... | xii |
| SALE OF TRANSACTIONS ... ... | x |
| SUBJECTS FOR PAPERS ... ... ... | xvi |
| TRANSACTIONS WANTED ... ... | xii |
| TUNNELLING COMPANIES, ROYAL ENGINEERS ... ... ... ... | iv |


*Contents continued on page xi.*

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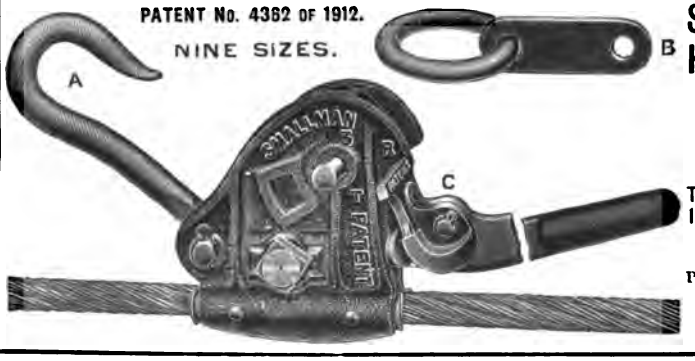


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## LIST OF ADVERTISERS.


| | PAGE. |
|---|---|
| Allan, Whyte, & Co., Clyde Patent Wire-rope Works, Rutherglen, Glasgow ... ... | iii |
| Bullivant & Co., Ltd., 72, Mark Lane, London, E.C. ... ... ... ... ... | xvii |
| Cooke & Co., William, Limited, Tinsley Steel, Iron, and Wire-rope Works, Sheffield ... | iv |
| Curtis's & Harvey, Limited, Cannon Street House, London, E.C. ... ... ... | ii |
| Davidson & Co., Ltd., "Sirocco" Engineering Works, Belfast ... ... ... ... | vii |
| Davis, John, & Son (Derby), Ltd., All Saints' Works, Derby ... ... ... ... | vi |
| Diamond Coal-cutter Co., Stennard Works, Wakefield ... ... ... ... ... | iii |
| Fletcher, George, & Co., Ltd., Masson and Atlas Works, Derby ... ... ... ... | vi |
| Hadfields, Limited, Sheffield ... ... ... ... ... ... ... ... ... | xviii |
| Henzell Oil Co., Northern Oil Works, Forth Banks, Newcastle-upon-Tyne ... ... | xiv |
| Mavor & Coulson, Limited, 47, Broad Street, Mile-End, Glasgow ... ... ... | vii |
| Pulsometer Engineering Company, Ltd., Nine Elms Iron Works, Reading ... ... | ii |
| Roburite and Ammonal, Limited, 103, Cannon Street, London, E.C. ... ... ... | v |
| Smallman, James W., Nuneaton ... ... ... ... ... ... ... ... | xi |
| Universal Mining School, Cardiff ... ... ... ... ... ... ... ... | ix |
| Walker Bros. (Wigan), Ltd., Wigan ... ... ... ... ... ... ... ... | xi |
| Wright, J. & E., Ltd., Universe Works, Birmingham ... ... ... ... ... | v |


*If the page number is absent, the advertisement does not appear in this issue.*

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# INDEX OF ENGINEERING SPECIALITIES.

*The advertisements of the firms mentioned under each heading can be found by referring to the List of Advertisers on page xv.*


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INDEX OF ENGINEERING SPECIALITIES.—*Continued.*

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**London, June 14th and 15th.**

**Newcastle-upon-Tyne, September 13th and 14th.**

**Pages i to viii and 699 to 746.**

**Plate VII.**

**See page ix for detailed Contents of Part.**

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FIRST.—Title-page, Contents, List of Officers and Council, pages i to viii.

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